AD-A050 618

AD-A050 618

HEAVY LIFT HELICOPTER FLIGHT CONTROL SYSTEM

Volume I - Production Recommendations

Boeing Vertol Company
P.O. Box 16858
Philadelphia, Pa. 19142

September 1977

Final Report for Period July 1971 - July 1975

Prepared for

U. S. ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND
P.O. Box 209
St. Louis, Mo. 63166

APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

Due to the termination of the HLH program, reports summarizing the strides made in many of the supporting technology programs were never published. In an effort to make as much of this information available as possible, selected draft reports prepared under contract prior to termination have been edited and converted to the DOD format by the Applied Technology Laboratory. The reader will find many instances of poor legibility in drawings and charts which could not, due to the funding and manpower constraints, be redone. It is felt, however, that some benefit will be derived from their inclusion and that where essential details are missing, sufficient information exists to allow the direction of specific questions to the contractor and/or the U.S. Army.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USAAMRDL-TR-77-40A	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HEAVY LIFT HELICOPTER FLIGHT CONTROL SYSTEM - Volume I, Production Recommendations		5. TYPE OF REPORT & PERIOD COVERED Final, July 1971 to July 1975
		6. PERFORMING ORG. REPORT NUMBER D301-10322-1
7. AUTHOR(s) A. J. Niven		8. CONTRACT OR GRANT NUMBER(s) DAAJ01-71-C-0840(P6A)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Boeing Vertol Company P. O. Box 16858 Philadelphia, PA 19142		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Aviation Research and Development Command, P. O. Box 209, St. Louis, MO 63166		12. REPORT DATE September 1977
		13. NUMBER OF PAGES 90
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Applied Technology Laboratory, Research and Technology Laboratories (AVRADCOM) Fort Eustis, VA 23604		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Volume I of a three-volume report.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopters	Control	Servomechanisms
Flight Control System	Electrical Equipment	Stalling
Automatic Pilots	Interfaces	Transducers
Cockpits	Test Equipment	Altitude

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report defines the requirements for the Heavy Lift Helicopter (HLH) flight control system. Production recommendations concerning the fly-by-wire mechanization concepts and the stability and control characteristics requiring augmentation are developed. This report constitutes Volume I of the overall HLH flight control system study. Associated documents are: Volume II - Primary Flight Control System Development and Feasibility Demonstration,

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block 19 (Cont): Hovering, Cargo, Stabilization Systems, Load Control, Detectors

Block 20 (Cont): and Volume III - Automatic Flight Control System Development and Feasibility Demonstration. Volumes II and III expand the basic requirements set forth in this volume.

PREFACE

In June, 1971 the tandem rotor configuration was selected for the HLH and the U.S. Army Aviation Systems Command ** awarded an Advanced Technology Components (ATC) contract DAAJ01-71-C-0840(P6A) to the Boeing Vertol Company for a development and proving effort on items considered critical to a successful HLH. These items were the rotor, drive, cargo handling, and flight controls systems.

This document has been prepared as a final report to the flight controls portion of the contract. As such, it reports upon the design-development and the demonstrations of the HLH type control system. The report is divided into three volumes:

Volume I	Heavy Lift Helicopter Flight Control System - Production Recommendations
Volume II	Heavy Lift Helicopter Flight Control System - Primary Flight Control System Development and Feasibility Demonstration
Volume III	Heavy Lift Helicopter Flight Control System - Automatic Flight Control System Development and Feasibility Demonstration

The definition of the production system made in Volume I was further advanced by the contract to build a prototype HLH. Although this contract was cancelled before completion because of a realignment of funding priorities, the degree of completion was high and the contribution to the definition in particular areas was significant.

The ATC program was conducted as a phased effort:

- Phase 1 consisted of a 6-month study to select the fly-by-wire mechanization concept and the stability and control characteristics requiring augmentation. Items considered critical to the HLH control system success were identified for further work. This activity was documented in an interim report (Reference 1).

- Phase 2 consisted of continuing development in the laboratory and in-flight feasibility demonstrations of the critical elements identified during Phase 1, and of making appropriate production vehicle recommendations.

**Redesignated U. S. Army Aviation Research and Development Command.

PREFACE (Continued)

-The development and proving phases are reported in Volumes II and III of this document. Production vehicle recommendations appear as Volume I.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF TABLES

THE HEAVY LIFT HELICOPTER

The Heavy Lift Helicopter (HLH), depicted in Figure 1, is a new aircraft developed by the United States Army. Power is supplied by three turboshaft engines, each rated at 8,079 horsepower. Design and maximum alternate gross weights are 118,000 and 148,000 pounds, respectively. External cargo payload at design gross weight is 45,000 pounds, under sea level/95^{O}F ambient conditions. The aircraft will nominally cruise at 130 to 145 knots; maximum forward velocity is 170 knots. At design conditions, the aircraft can fly two sorties of a 25-nautical-mile radius each, deposit a 45,000-pound payload at the end of each outbound leg, and return empty. Precise maneuver capability, external load visibility, and winch control is provided by a third, rear-facing pilot (referred to as the load controlling crewman, LCC) for rapid external load acquisition and delivery.

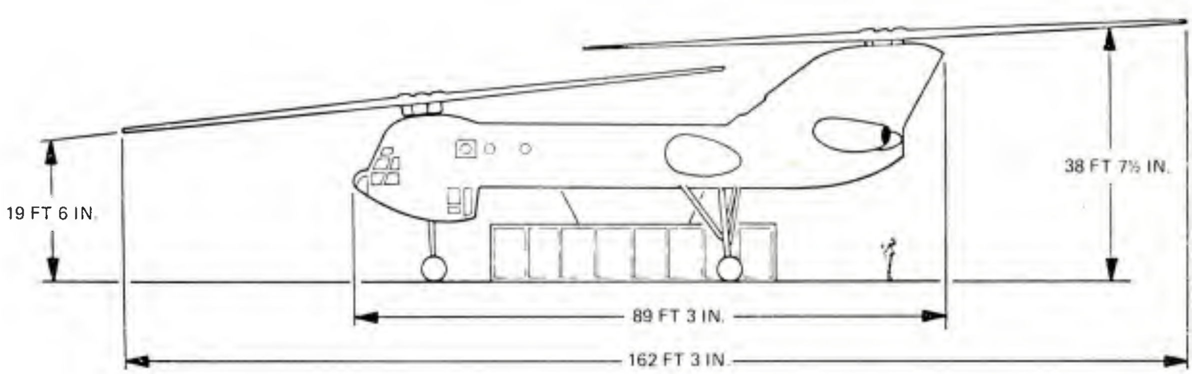


Figure 1. U.S. Army Heavy Lift Helicopter

THE PRODUCTION HLH FLIGHT CONTROL SYSTEM

INTRODUCTION

This volume presents recommendations relating to the production HLH Flight Control System and provides a description of the recommended system and its characteristics.

- Section I - relates to the Primary Flight Control System (PFCS)
- Section II- relates to the Automatic Flight Control System (AFCS)
- Section III- discusses the development status of both the PFCS and AFCS elements.

CONCEPTS

The concepts upon which the flight control system are based were selected for their suitability to the HLH mission. Principal concepts are:

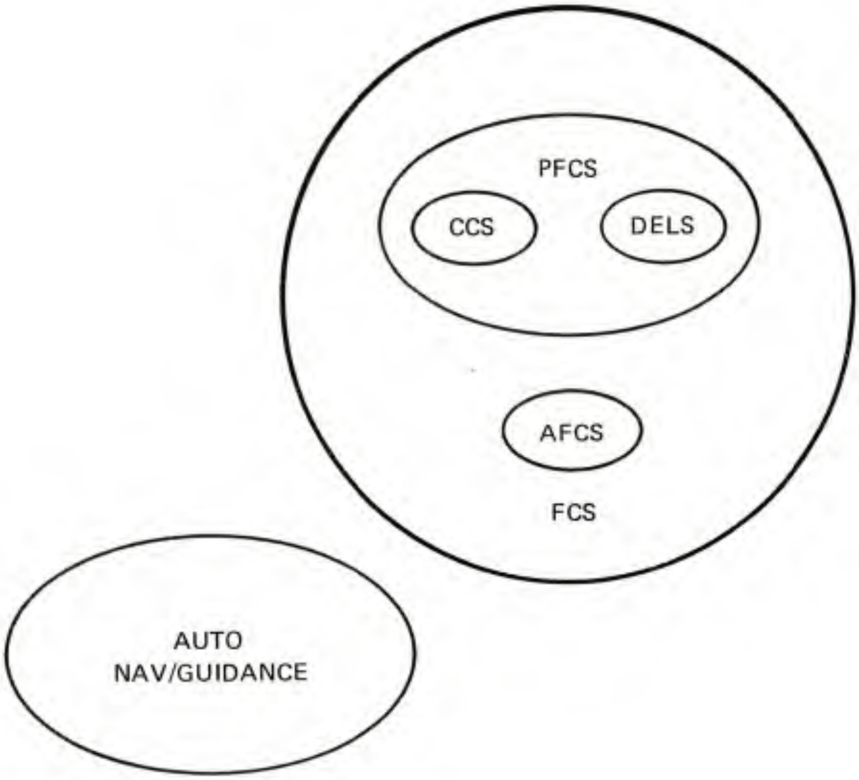
- Improved cockpit controls of the conventional type, designed to allow comfortable, precise control, and low hazard vulnerability.
- A reliable electrical primary control linkage (fly-by-wire) with simple guarded access to inputs from other systems.
- A stability and control augmentation system with selectable modes as appropriate to each portion of the total mission.

Each of these concepts was enumerated in the Task I trade studies of the ATC program (Reference 1).

FCS ORGANIZATION AND STRUCTURE

As illustrated in Figure 2, the flight control system contains a PFCS and an AFCS. The PFCS is further subdivided into the DELS and the CCS, as discussed below:

The PFCS is a multi-redundant electrical equivalent of a power-operated conventional mechanical control system which constitutes a direct linkage between the pilot and the rotors. Position transducers are connected to conventional cockpit controls, the outputs of which are processed within the Direct Electrical Linkage System (DELS) and used to operate electrohydraulic actuators controlling the rotors.



FCS = FLIGHT CONTROL SYSTEM

CCS = COCKPIT CONTROL SYSTEM

DELS = DIRECT ELECTRICAL LINKAGE SYSTEM

PFCS = PRIMARY FLIGHT CONTROL SYSTEM

AFCS = AUTOMATIC FLIGHT CONTROL SYSTEM

Figure 2. Flight Control System Organization

Key Features of The PFCS are:

- A fly-by-wire system with three separate channels, one of which is master and the other two compliant.
- Two-fail operational characteristics by which the system may lose two channels to failure and still maintain operation.
- High flight safety reliability (.99999990 for the entire flight control system for a 2-hour mission or one loss in 2×10^7 flight hours).
- Low vulnerability to damage by separation of redundant elements. Designed for high damage survivability.
- Simple built-in test equipment (BITE) with fault isolation capability.

The AFCS performs stability control augmentation, nav/guidance coupling, and selectable modes required for various missions. The redundancy of the parts is set according to the importance of the mission.

Key Features of the AFCS are:

- Precise helicopter control characteristics for load acquisition and deposition.
- Handling qualities and reliability characteristics for IFR operation.
- Selectable modes
- Whole-word digital mechanization.
- Load controlling crewmember interfaces.

REQUIREMENTS AND OBJECTIVES

The requirements and objectives to which the flight control system of the production HLH was designed are stated in the ATC statement of work (Reference 2) and amplified in the Prime Item Description Document (PIDD) (Reference 3).

The handling qualities' requirements and objectives which further the ability of the helicopter to perform its mission and which are of particular interest to the presentation of the configuration are:

- Simplify the piloting task

- Optimize vehicle handling qualities

- Minimize pilot switching modes of operation between flight regimes and eliminate transients introduced as a result of mode switching or control transfer between pilots.

Performance goals for the augmented aircraft included:

- Providing the pilot with a precision control capability to position the helicopter (or load) within ± 4 inches vertically and horizontally and $\pm$ 2 degrees in azimuth with respect to a selected reference within two minutes, starting from a point several hundred feet away from the target, under gusty conditions, with steady wind velocities up to 45 knots applied from any azimuth.

- Providing positioning of the helicopter over a load after cable attachment and automatic load stabilization capability permitting IFR operations without pilot stabilization inputs.

In addition to meeting the handling qualities and performance objectives stated above, Reference 3 stipulates that the requirements of MIL-H-8501A with approved Army deviation should also be adhered to in design of the HLH flight control system.

Redundancy management objectives are to maintain full operational capability of the DELS after two identical failures have been incurred, and to maintain AFCS computational capability after any single failure has occurred and to provide a safe shutdown for a second failure. (Specific sensor redundancy may vary as appropriate to the AFCS modes.)

ASRD, Reference 4, is the source of the objectives and requirements.

<u>Subsystem Relationships</u>

A general diagram showing the relationship of subsystems of the flight control system to each other and to their major interfaces is shown in Figure 3.

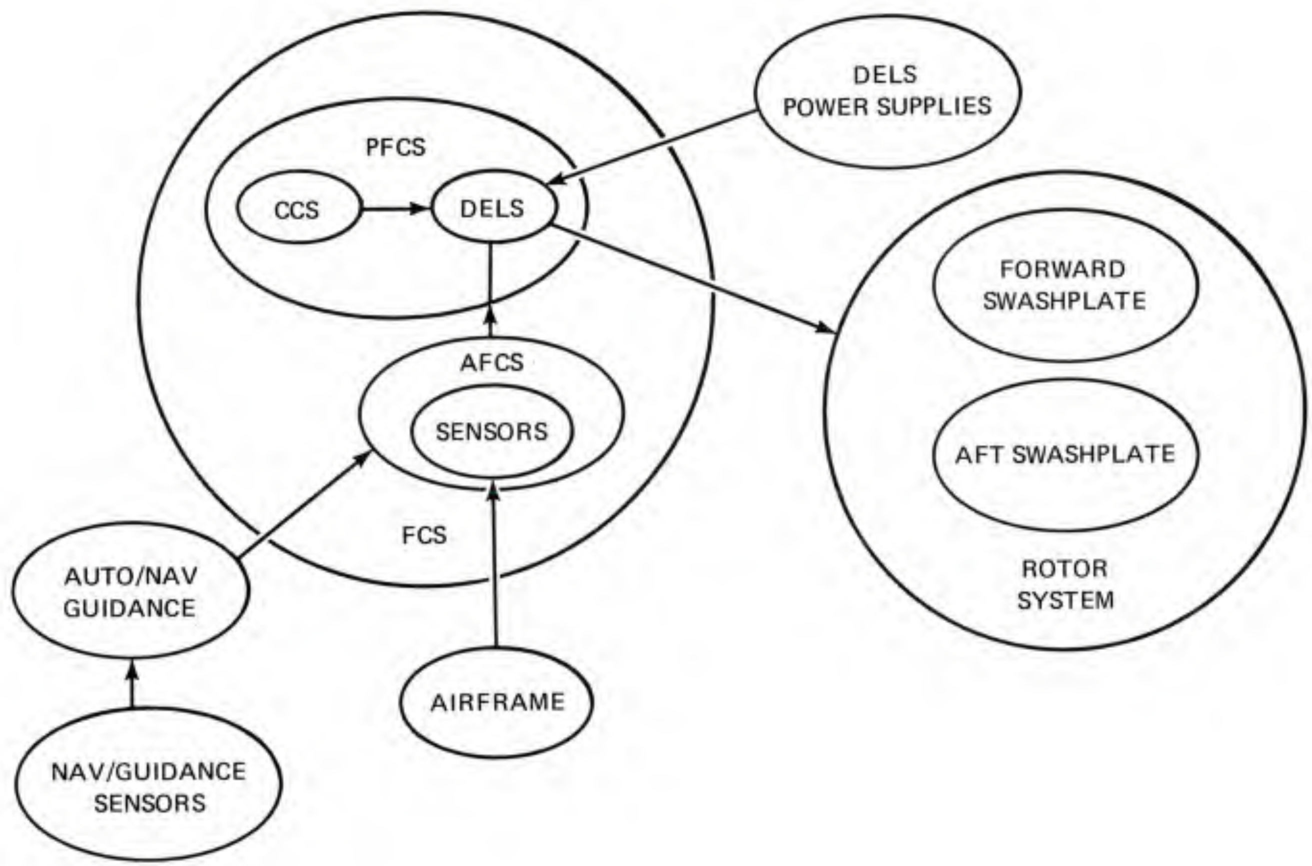


Figure 3. Subsystem Relationships

PRIMARY FLIGHT CONTROL SYSTEM

Cockpit controls consist of a cyclic stick, pedals, and collective lever as in a conventional helicopter. In addition, a rotor longitudinal cyclic pitch adjustment is provided. The controls, rotor blade effect and use are listed in Table 1.

TABLE 1. PRIMARY FLIGHT CONTROL SYSTEM

COCKPIT CONTROLLER		ROTOR BLADE EFFECT	USE
"Cyclic" Stick	1	Differential Collective Pitch	Aircraft Longitudinal Control
	2	Lateral Cyclic Pitch	Aircraft Lateral Control
Pedals	3	Differential Lateral Cyclic Pitch	Aircraft Directional Control
Collective Lever	4	Collective Pitch	Aircraft Vertical Control
LCP	5	Longitudinal Cyclic Pitch, individual control at each rotor	Aircraft Drag,Noise, and Attitude Trim Adjustment

The two parts of the PFCS, the CCS and the DELS, are described below.

DIRECT ELECTRICAL LINKAGE SYSTEM (DELS)

DESIGN APPROACH

The electrical control linkage between the cockpit controls and the forward and aft swashplates is an electrical analog implementation driving into electrohydraulic swashplate servo actuators.

Three independent and separate channels are provided, each capable of performing the flight control function without assistance from the other two.

The three channels are brought together at the swashplate servo actuator, at which point they are force-summed.

In operation, one of the channels is controlling master. This role is transferred to other channels as the channel's failure status requires.

Electrical interfaces with other systems have protective buffers to avoid damage to the DELS from external sources.

Inputs from the AFCS are guarded by authority and rate limits so that effects of AFCS derangement are constrained to a level which is allowable from a flight safety viewpoint.

DESCRIPTION

The DELS is an electrical linkage which couples the cockpit flight controls of the HLH to the forward and aft swashplates on a functional basis, as shown in Figure 4.

Each swashplate is supported and controlled by three approximately equally spaced swashplate servo actuators. These actuators are of the integrated electrohydraulic type.

At the input, stick position transducers (SPT) are attached to the cockpit controls to generate electrical signals proportional to control displacement. These are then transmitted as control commands to the linkage electronics for processing and translation to swashplate servo actuator commands.

MAJOR PHYSICAL PARTS

The DELS is composed of four major components as indicated in Figure 5; the DELS Control Units (3 units), Swashplate Servo Actuators (SSA) (6 units), Panels (1 aircraft set), and Stall Damper Units (2 units).

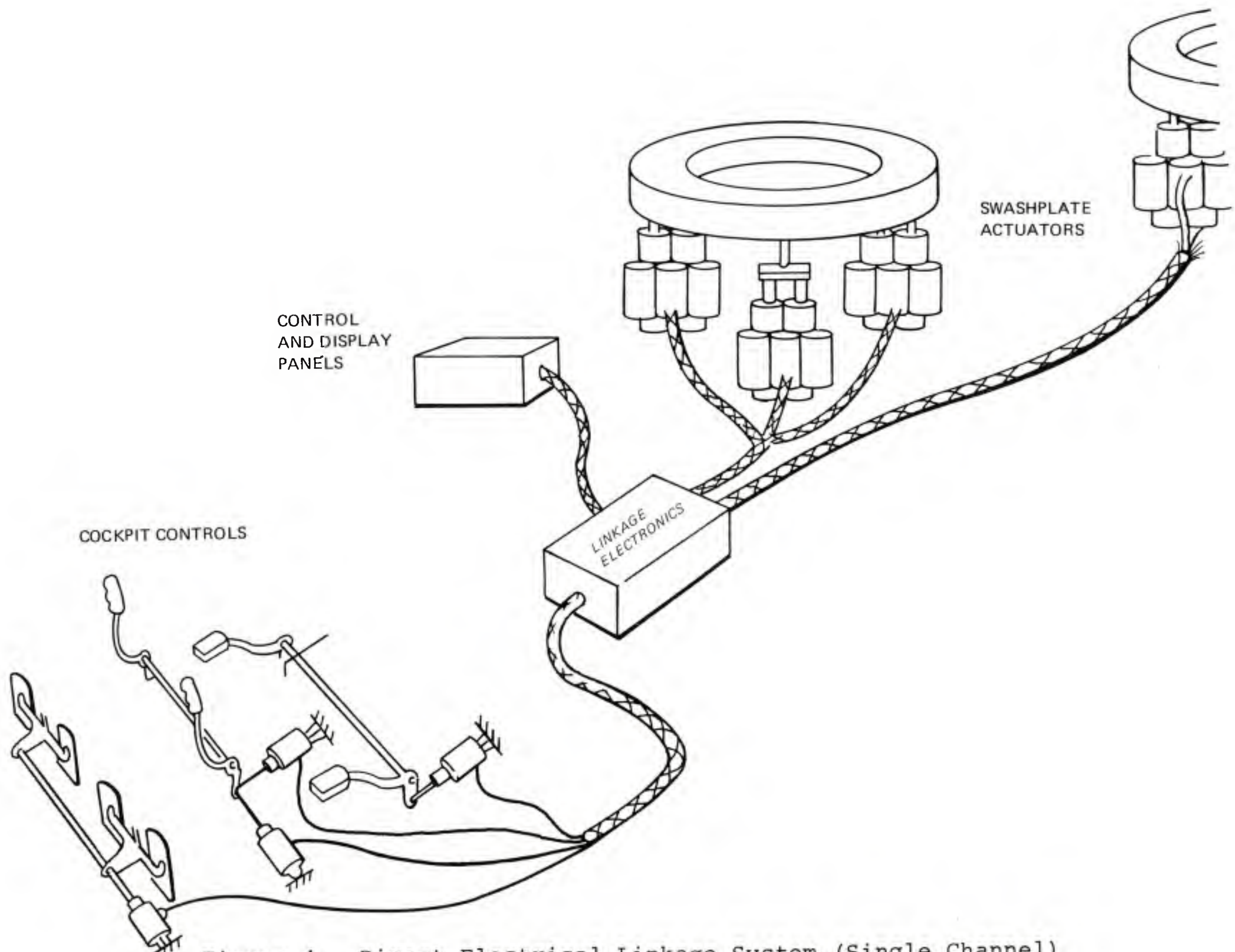


Figure 4. Direct Electrical Linkage System (Single Channel)

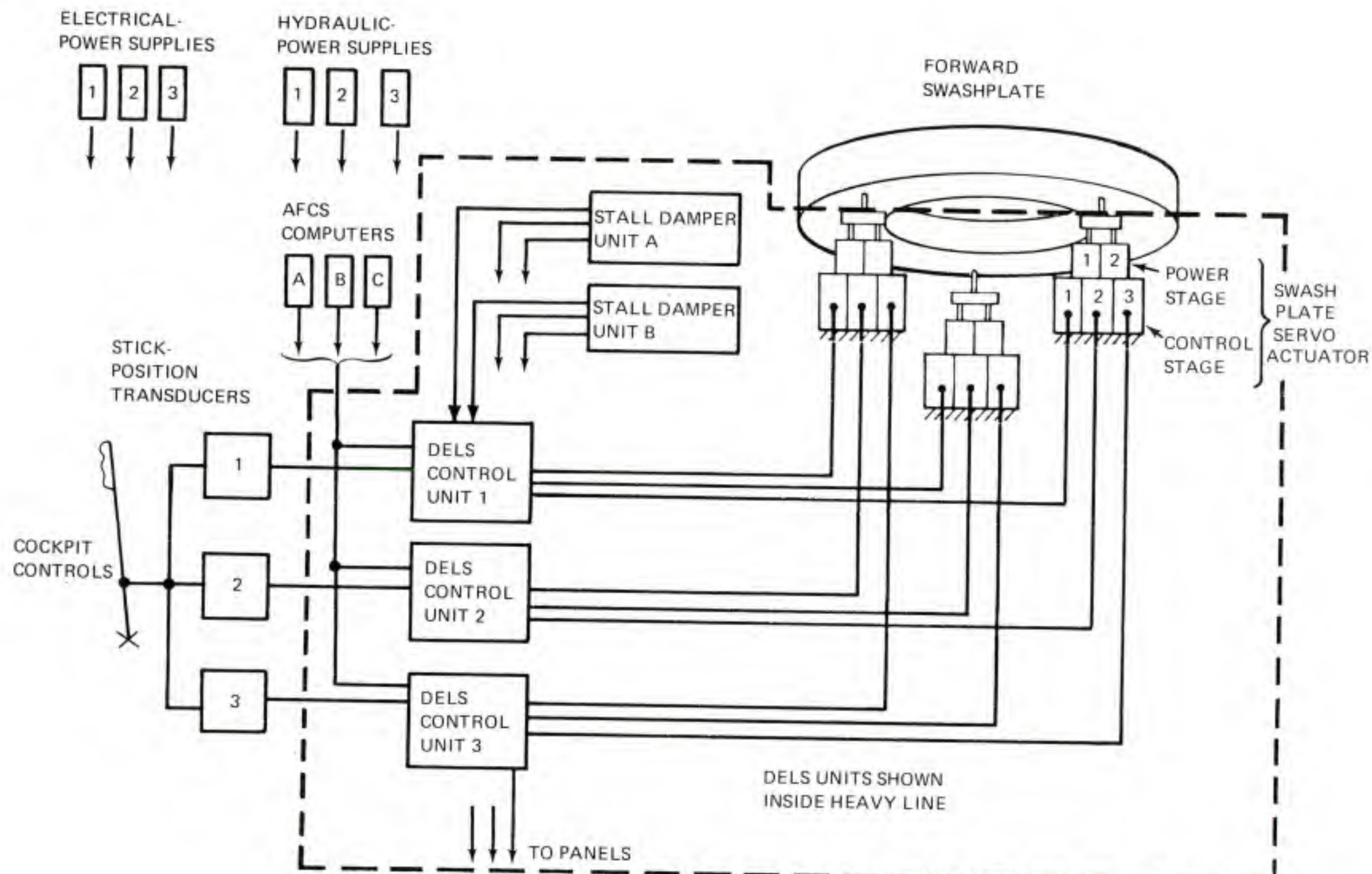


Figure 5. Simplified Block Diagram of DELS

These components are arranged to serve three channels of the DELS as depicted in the equipment diagram appearing as Figure 6.

FUNCTIONAL AREAS

The following functions are performed within the DELS:

Motion Sensing

Stick position transducers convert pilot stick and pedal motions to proportional voltages.

AFCS Interfacing

The DEL control unit provides the signal interfacing between the DELS and the AFCS.

Mixing

The DEL control unit mixes the signals from the cockpit controls and the AFCS in a manner suitable for distribution to the swashplate servo actuators.

Swashplate Actuation

The DEL control unit provides the SSA servo loop electronics and the swashplate servo actuator converts signals from the mixers to mechanical motions which position the swashplate.

Failure Detection

Each DEL control unit provides failure detection for the DELS channel to which it belongs and provides signals to the mode control logic.

Mode Control

The DEL control unit processes the signals received from the failure detection circuits and sends signals to the swashplate servo actuator bypass valves and to the status/BITE control.

Status Display and BITE Control

The DEL panels provide monitoring, display, and test capabilities to:

- Assess the number of operable success paths in the DELS
- Provide logic to drive the aircraft master caution and caution/advisory panels

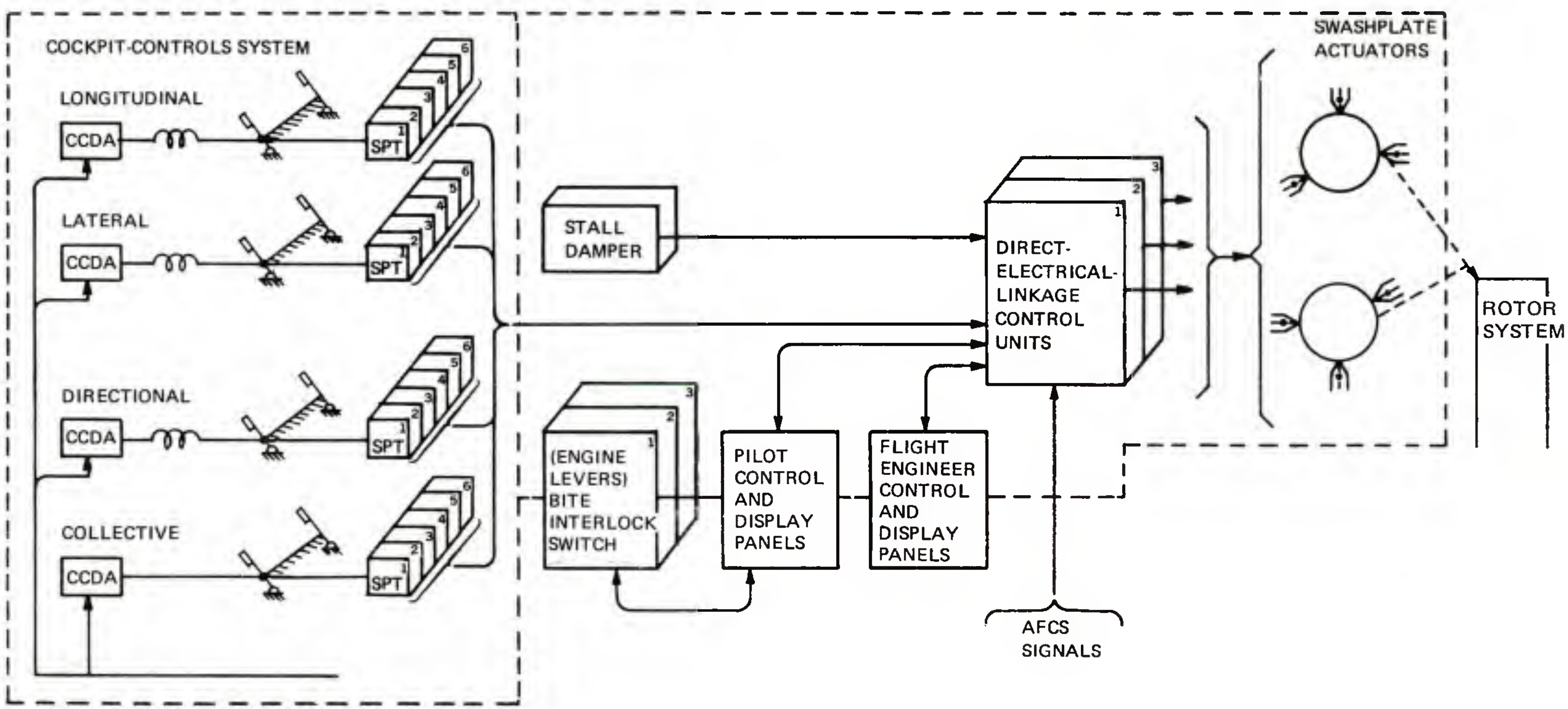


Figure 6. DELS Equipment Diagram

- Reset failed channels in the DELS
- Conduct go/no-go ground tests on each DELS channel and each channel in the AFCS interface.

Fault Isolation

The DEL control unit contains an interrogation circuit for fault isolation purposes.

Swashplate Servo Actuator Load Monitoring

The SSA load monitor monitors swashplate servo actuator loads. It indicates occasions when loads occur beyond a predetermined level.

Stall Flutter Damping

The stall damper unit causes damping motions in the swashplate servo actuators to stall flutter torsional rotor blade modes.

The stall flutter frequency is seen as 4/rev at the actuator.

Differential pressure signals received from the power stages of the swashplate servo actuators are processed by the stall damper control units for distribution to the DEL control units.

SIGNAL FLOW

Signal flow through the DELS is as indicated in the diagram of Figure 7. The signals are mixed and limited as they proceed, in the following manner.

Signals generated by stick position transducers attached to the cockpit controls are transmitted to the DEL control unit where they are summed on an axis basis with signals from the AFCS. The AFCS signals are authority and rate limited before this summation is made. Each axis signal is then modified by an appropriate axis gain.

Combinations are then formed of collective + DCP signals and lateral + direct oral signals. Each combination is then authority limited to allow a suitable apportionment of the downstream swashplate actuator authorities. Because the swashplate actuator authorities are less than the sum of the axes command ranges these combination limits are important to the prevention of one signal pair absorbing an unreasonable portion of the total range.

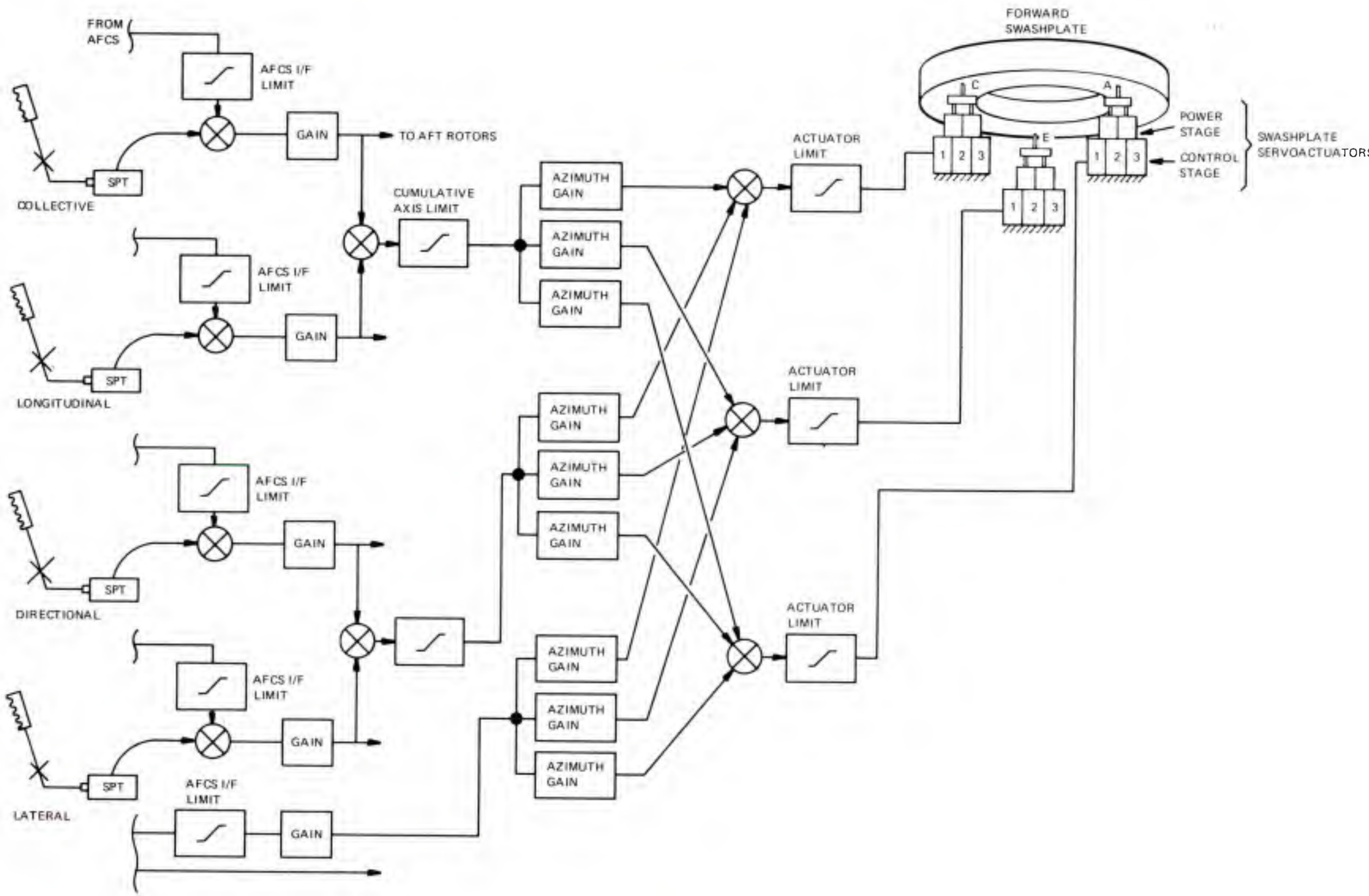


Figure 7. DELS Signal Flow

Longitudinal cyclic pitch signals via the AFCS interface are limited independently.

These signals, cum-collective, cum-lateral, and LCP are combined in proportions appropriate to the azimuth locations of each swashplate servo actuator; one signal for each actuator.

Finally, each signal is then authority limited and supplied as the command signal to the servo loop electronics of each swashplate servo actuator.

Figure 7 shows the signal flow for the forward rotor head. The aft rotor head is similar in signal flow but the sign of the signal summation and the values of gain are different.

Servo Loop

Figure 8 shows a simplified diagram of the servo loop of the swashplate servo actuator. The loops involved are control stage position, control stage delta pressure, power stage position, and power stage delta pressure.

The control stage delta-P is used as part of the redundancy management technique, described later.

Power stage delta-P is used as sensing for stall flutter damping purposes.

Stall Flutter Damping

Each stall damper control unit receives signals from a pair of sensors measuring delta pressure across the control stage pistons for each swashplate servo actuator; one of the pair senses for system one and the other for system two. The signals are combined so that the sum represents the total load on the actuator (see Figure 9).

The combined signals are passed through filters which pass frequencies in the 4/rev region and are shaped to achieve motions at the actuators which have a damping phase (at appropriate gain) to the stall flutter motions which are impressed upon the actuators from the rotor system.

The signals are authority limited before being connected to the appropriate servo loop summing points.

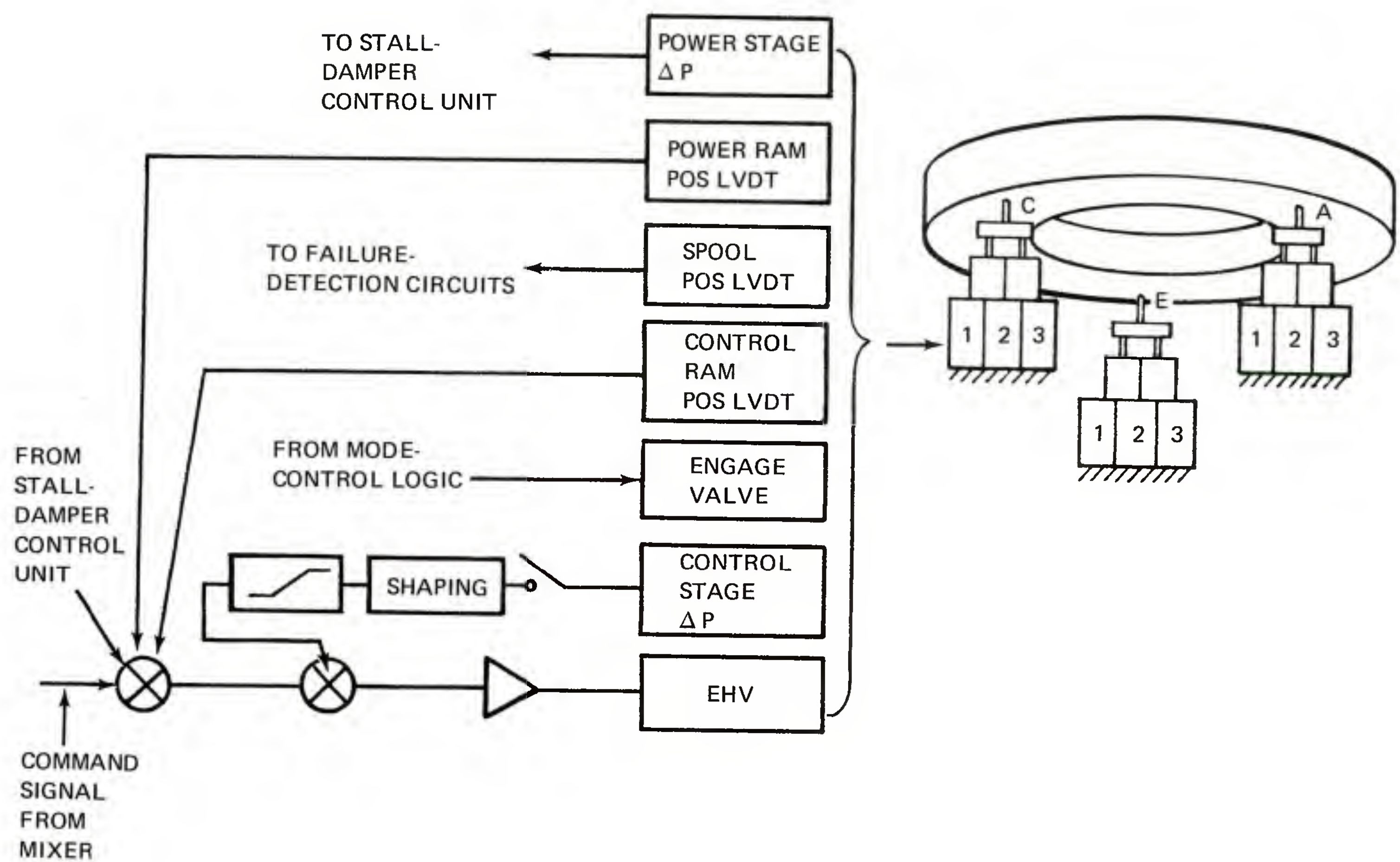


Figure 8. Swashplate Servoactuator Servoloop

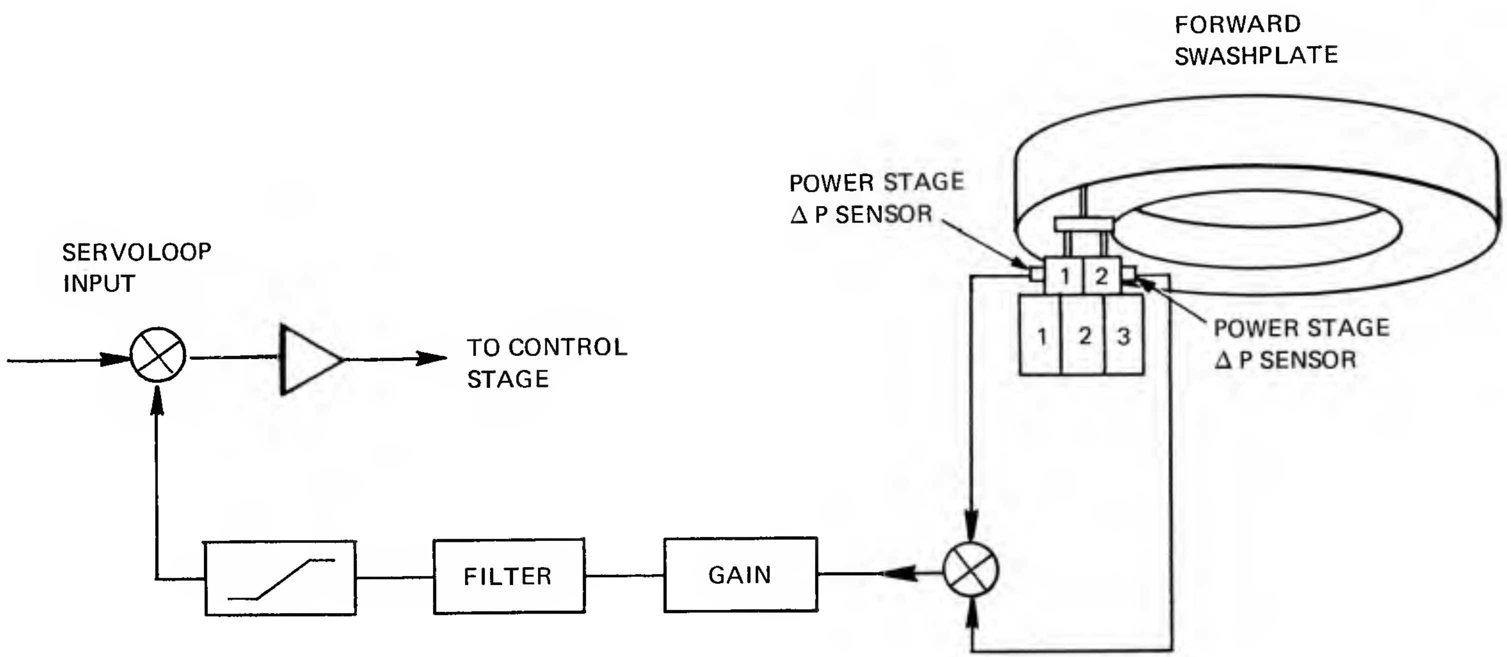


Figure 9. Stall-Damper Diagram (Single Loop)

EXTERNAL INTERFACES

Because the DELS provides the primary flight control function, it is mechanized as an independent subsystem with limited contact with other aircraft systems. Where interfaces with other systems are established, the interfaces are designed to prevent degradation of the DELS by external events. The following are the interfaces with other systems and subsystems.

Cockpit controls - this is a mechanical interface with the stick position transducers.

Swashplates - this is a mechanical interface with the swashplate servo actuators

Electrical power supplies - this is an electrical interface with the DEL control units.

Hydraulic power supplies - this is a hydraulic interface with the swashplate servo actuators to provide a power source for swashplate control.

Engine control system - this is an electrical interface with the DEL control units. Signals are provided by the DELS to the engine control system to allow engine settings to be made as a function of collective axis commands at the cockpit controls.

Ground power interlocks - this is an electrical interface with the DEL control units. DELS failure-status signals are provided by the DELS to the ground power interlocks to inhibit the application of ground hydraulic power when the DELS is not in start-up status.

AFCS - this is an electrical interface with the DEL control units. Incoming AFCS signals to the DELS are for vehicle stability and control augmentation in vertical, longitudinal (DCP), directional, lateral, and longitudinal (LCP). Outgoing signals from the DELS provide cockpit control position information to the AFCS.

REDUNDANCY MANAGEMENT

Redundancy - Main Elements

The pages immediately preceding this section have described the functions and form of a working electrical linkage.

Flight safety and mission reliability objectives require three complete, independent, and separate DELS channels, each capable of performing the flight control function without assistance from the other two. In addition, failure transient suppression of a high order is necessary.

Figure 10 indicates the three channels connecting the cockpit controls to the swashplate. The three channels come together at the swashplate servo actuator. The actuator has a duplex power stage and a triplex control stage, one for each channel of the controlling electronics.

The outputs from the three control-stage channels are connected commonly in a force-summing manner as indicated in Figure 11. Channel number one is designated as the "active" (master) channel, and the other two are made to be "on-line" (compliant) over a limited range of force disagreement by the application of an authority-limited differential pressure feedback loop around each of the channels to be compliant.

Should a failure occur in any channel, the failure is detected within the channel and it is shut down. Should the failure be in the active channel, another is converted to "active" status by switching out the differential pressure feedback.

If a failure occurs which affects only one swashplate servo actuator, then the affected actuator is shut down and not the entire channel.

Two entire channels may be lost by failure and the flight control function is performed by the third. Further shutdown is inhibited to prevent all three channels from being shut down at any time.

A low-pass filter is present in the path of the differential pressure signals. This has the effect of conforming the "on-line" compliance to the low frequency domain so that suppression of transients from high rate failures is emphasized. This means that after a first failure, should the "active" channel fail to bypass hydraulically, the "on-line" channels will maintain normal operation by over-powering the failed channel. Hence, the logic switching is not time critical for a first failure.

Because the differential pressure signal is authority limited, the long-term offset resulting from an unswitched failure is confined.

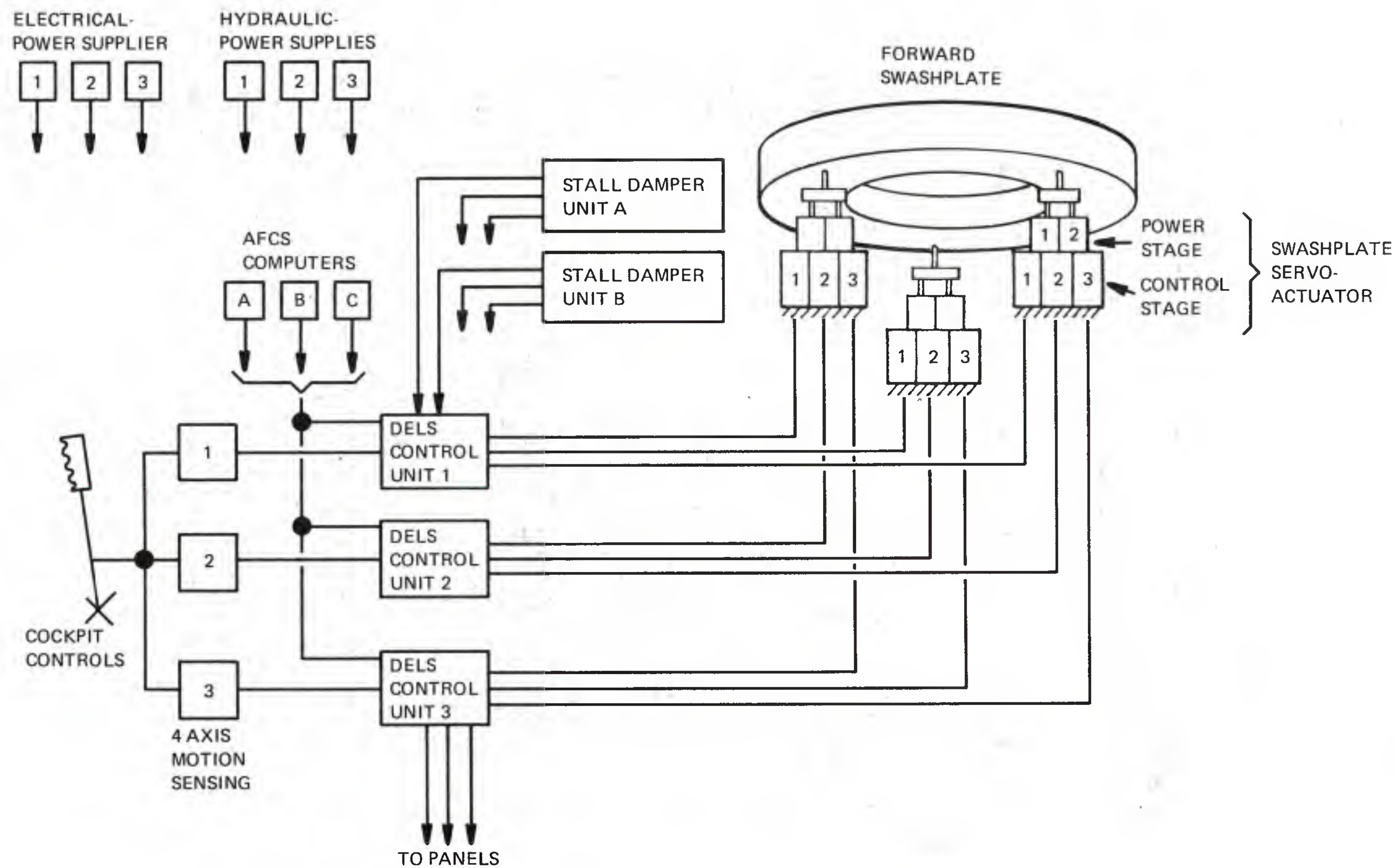


Figure 10. DELS Simplified Block Diagram

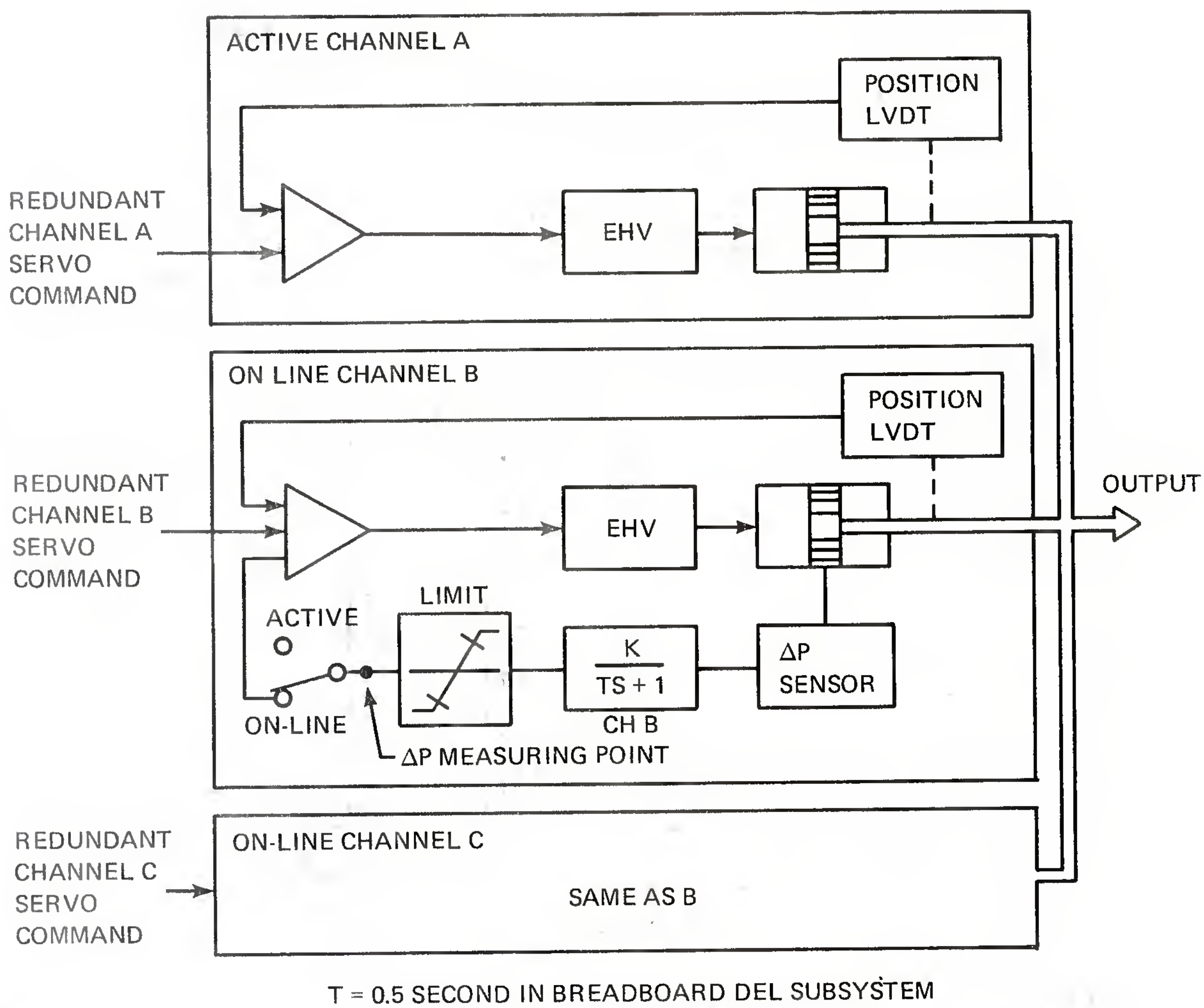


Figure 11. Active/On-Line Actuator Control Concept Diagram

The long term offset resulting from switched failures is a function of the tolerances allowed between channels. ATC program experience along with DELS specifications predict this to be no problem.

Redundancy - Other Areas

AFCS Interface - The AFCS is triplex. It has monitoring circuits which allow it to detect failures which occur within its domain.

Signal processing is included within DELS such that the AFCS cannot degrade the DELS reliability by causing DELS channel shutdowns. This is accomp.ished by having each DELS channel vote all AFCS signals so that failures which occur downstream of AFCS monitoring circuits may be rejected. When such failures are detected, the affected AFCS channel is shotdown in the DELS.

The AFCS is shutdown entirely for a second such failure in the remaining channels and the aircraft is flown by means of the DELS, without augmentation inputs.

The AFCS interface circuitry within the DELS is designed to provide aircraft protection from large authority AFCS hardovers such as could result from programming errors in the AFCS. The signal processing consists of passing the AFCS signal through high frequency-low authority and a low frequency-high authority paths.

The hardover failure signal from the AFCS results in an initial low-amplitude step followed by a ramp to a limited value. The initial step is limited to acceptable high frequency transient levels while the ramp signal is related to static trim changes which are not time critical. This concept was verified in the ATC flight program.

Stall Flutter Damping

Stall flutter damping is mechanized in duplex form. Disparity between stall flutter signals above a predetermined level causes a disengagement of the stall flutter damping mode.

The swashplate servo actuator load monitor, mechanized within the stall damper control unit, is simplex. This function does not require redundancy because it involves little effort to check it on a periodic basis.

Electrical Power Supplies - One independent electrical power supply is provided for each DELS channel (three in all). These originate at three transmission-driven, permanent, magnet generators which supply nothing but DELS.

Two of these are driven by the forward transmission and one by the aft.

Each of these supplies are provided with batteries for emergency use.

Hydraulic Power Supplies - Both of the control and power stages of the swashplate servo actuators for channels one and two at the forward rotor head are hydraulically powered from two independent systems having pumps driven by the forward transmission.

Similarly, the actuators of channels one and two at the aft rotor head are powered from two independent systems having pumps driven by the aft transmission.

The third channel of control stages of actuators at the forward and aft rotor head are commonly driven by an electrically driven motor pump.

Hydraulic lines connect the forward and aft hydraulic systems for channel one and the forward and aft systems for channel two. These lines are not normally pressurized but in the event of a failure of a hydraulic system at the forward or aft head, the connecting lines are activated so that power may be supplied by a counterpart system from the opposite end of the helicopter.

Failure Detection

Failure detection within each DELS channel is self-contained as a means of preserving channel independence and separateness.

Generally, two signal paths are provided throughout each channel (in-line monitoring) and these are cross-compared at various points; Figure 12 is presented to illustrate this.

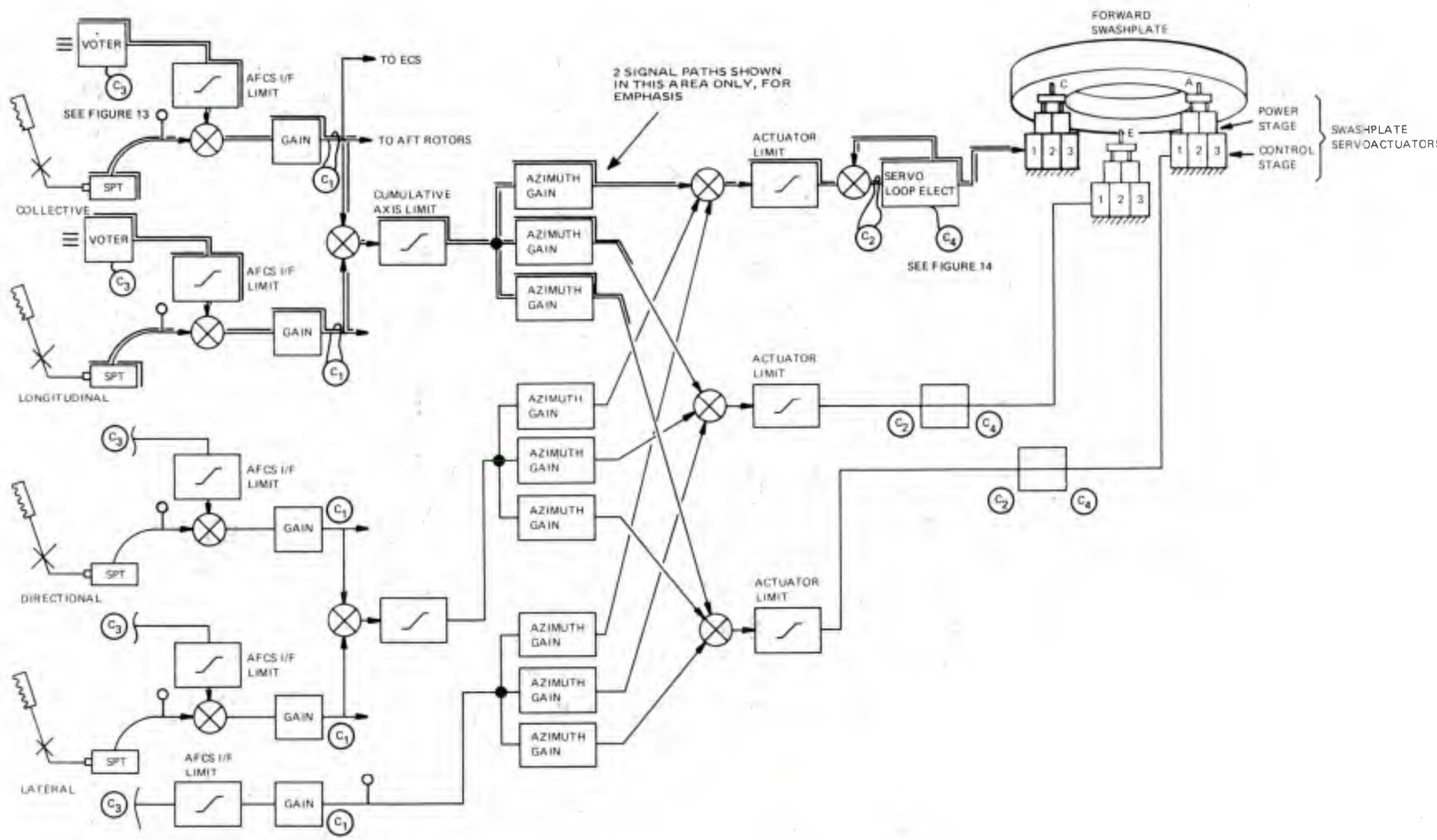


Figure 12. DELS Failure Detection (Forward Rotor Head, Channel 1)

Four failure detection groups are used:

- Group C_1 - used for the comparison of the combination signals of SPT + AFCS.
- Group C_2 - used for the comparison of command signals to the actuator servo.
- Group C_3 - used for comparison of signals in the AFCS interface.
- Group C_4 - used for the comparison and monitoring of signals within the servo loop of the swashplate servo actuator.

The detection thresholds at which a failure is declared to be present are set at a level greater than 2 X 3 Sigma tolerances which exist at the failure detection point. This threshold setting is aimed at adequate detection sensitivity for passive failures without incurring an incidence of nuisance trips.

Failure detection group C_2 gives an overall check of the signals from the stick position transducers at the cockpit to the point where the signals are delivered to the swashplate servo actuators as commands. Because of the ratios necessary in axis mixing, the detection threshold settings at C_2 are not sufficiently sensitive for upstream failures in all areas.

The longitudinal axis, for example, requires additional premix failure detection to achieve adequate sensitivity. This is provided by failure detection group C_1.

Group C_1 failure detection may not be needed for the vertical and directional axes where the mixing ratios are close to unity. Consideration is being given to their removal for these axes during the HLH prototype program.

Signals from the three AFCS channels are voted by each DEL control unit to identify failures which are fed to the DELS from this source; Figure 13 indicates the technique.

The median signal of the three presented to the voters is selected for use. Signal comparisons (C_3) are made as part of the voting process and lack of similarity beyond preset threshold levels causes the deviant signal to be recognized as failed. The failure detection logic causes adjustments to be made so that a failed signal is removed from the selection process.

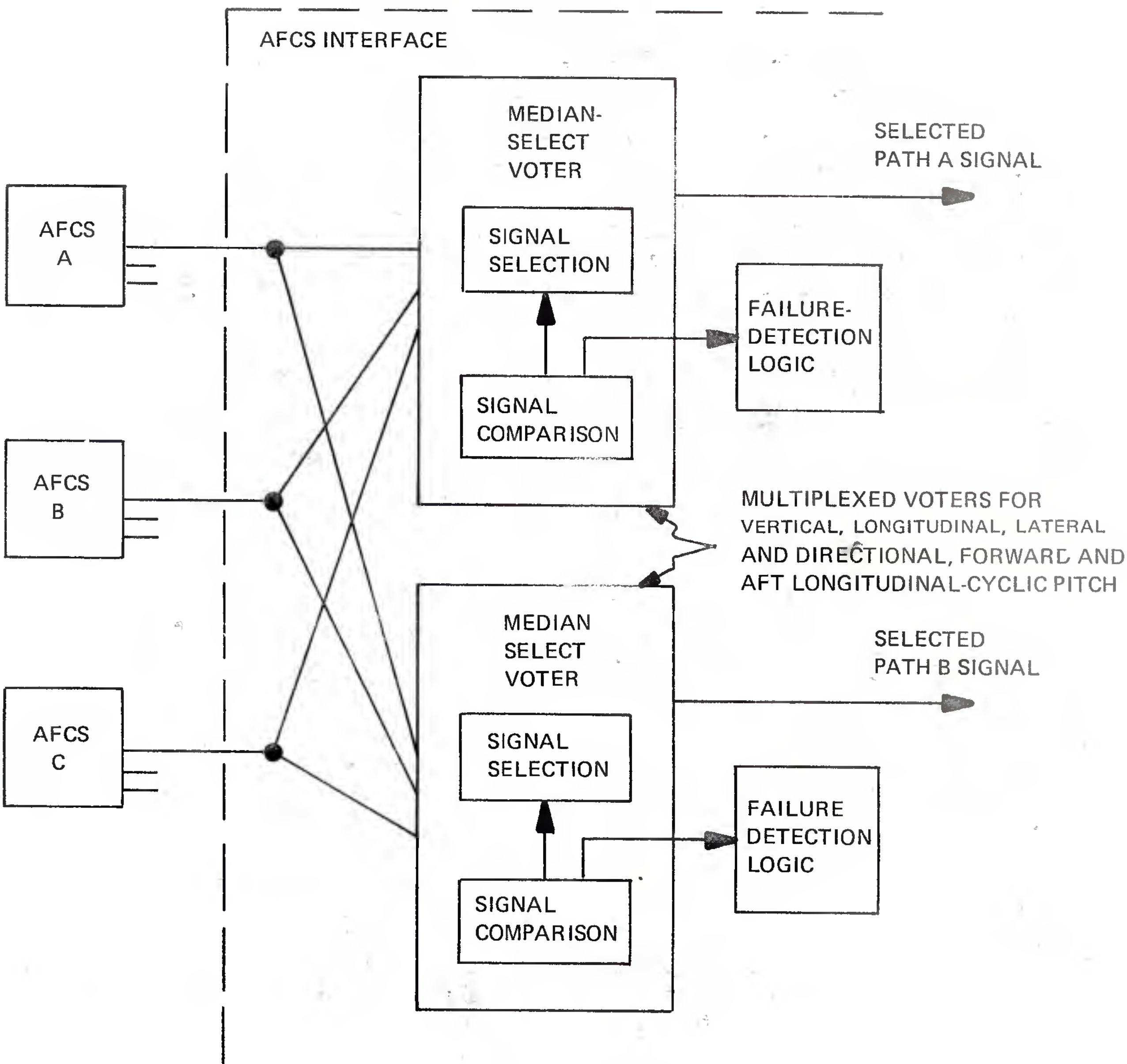


Figure 13. DELS AFCS Interface

Further failures cause the AFCS to be shut down.

Signal voting is performed in a duplicate manner in each channel to ensure that voter failures are detected. The voters are mutiplex in terms of vertical, longitudinal, lateral, directional, longitudinal cyclic pitch-forward, and longitudinal cyclic pitch-aft.

The servo loop is monitored in a variety of ways to assure detection of failures.

A model of the servo amplifier and the electrohydraulic valve is generated as is shown in Figure 14, so that failures in the electronic elements of the loop may be detected by comparison monitoring. The current in the electrohydraulic valve is verified by a comparison with a current in an electrical load which simulates the electrohydraulic valve in the model.

A position transducer (LVDT) is attached to the second stage spool of the electrohydraulic valve. The LVDT output, representing spool position, is compared to a filtered electrohydraulic valve command signal. Differences above a predetermined level are taken to indicate the presence of a failure. The filter allows some differences to exist dynamically.

Monitors are provided for the control stage position transducers, control stage delta pressure transducers, and the power stage position transducers to avoid the need for dual sensors at these points.

The control stage delta pressure transducers have an overtravel position to which they move when hydraulic pressure is removed. An electronic detector for this condition is used to indicate pressure loss.

Stall flutter damping failures are detected by direct comparison of the two channels of this duplex function. The detection circuits are contained within the DEL control units close to the point of signal entry. In the event of a failure, the stall flutter damping function to the affected actuators is shut down automatically.

<u>BITE</u> - Facilities are built into the DELS to allow the system to be tested for failures as a routine in the preparation of the aircraft for flight.

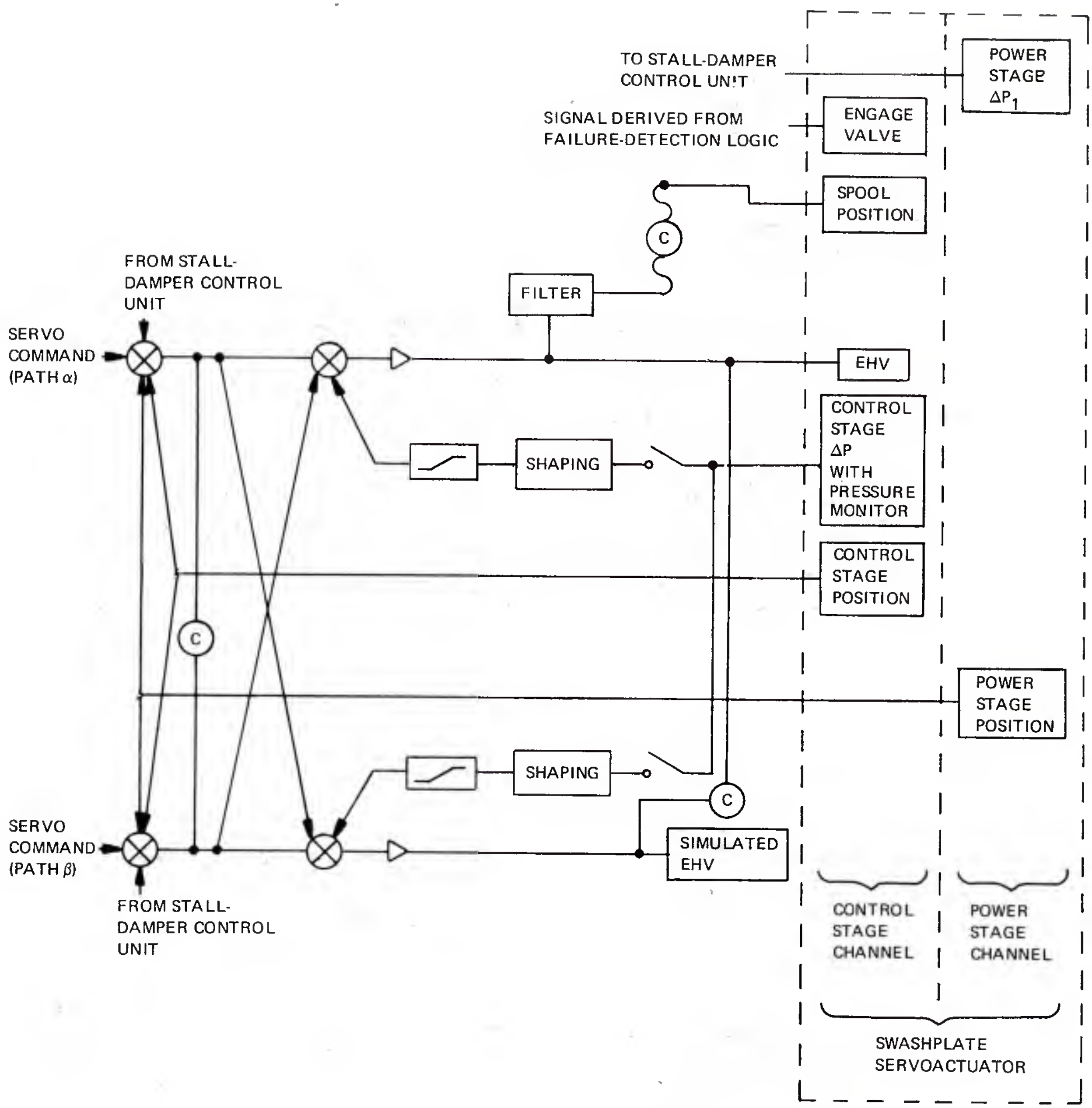


Figure 14. Servoloop Failure Detection

The primary BITE function is to ensure that the system is free of passive failures (active ones are immediately detected and announced).

The function of the BITE is to:

- Determine that all failure detection circuits are operational.

- Determine that all fail-passive elements are operational; i.e., all actuator bypass valves operate, all fail-soft elements such as triplex voters shutdown on second failure, all active/on-line swashplate servo actuator switching from channel-to-channel operates, and determine that signal paths are free of passive failures (electrical, mechanical, and hydraulic).

The BITE circuits automatically insert simulated failures into the signal paths at selected points to ensure that the failure is properly detected and to ensure that the correct response to the failure condition results. The BITE is automatically sequenced through the test schedule.

After this test, the failure detection and the corrective system response are both known to be completely operational. At this point, the cockpit controls are boxed manually and an interchannel tracking test is performed to ensure that the proper responses occur at the swashplate servo actuator and that no failure indications result during the exercising of controls.

Channel tracking is checked by the monitoring of swashplate servo actuator control stage delta-pressure (channel mis-track causes the development of a force disparity between channels and a resulting delta-pressure).

A BITE-Arm switch is provided in the cockpit. This is inter-locked with the engine condition levers to avoid inadvertent arming of the BITE circuits in flight.

Test clearance annunciator lights indicate satisfactory completion of test.

If a failure is present in the system during test sequencing, the test is automatically stopped at the test failed position. The BITE will not proceed until the failure has been cleared. The failure cannot be bypassed.

PANELS - Figure 15 shows the status and control panels associated with the DELS, in diagrammatic form.

The DELS monitor panel is for:

- Primary cockpit annunciation of DELS channel failures
- Reset of channels failed from nuisance incidents
- BITE arming

The BITE panel is for:

- Control and display of BITE status

The Failure/Status panel is for:

- The collection, display, and retention of failure location information for maintenance purposes.

LOAD MONITOR - SWASHPLATE SERVO ACTUATOR - Inflight steady state and alternating loads are fed back upon the swashplates from the rotor blades. The loads vary as a function of flight condition. The dual power stage of the swashplate servo actuators is sized to take these loads over the actuator life.

Should the load sharing between the two portions of the power stage become significantly unbalanced, as would occur if a severe leak developed across a piston seal, one side of the power stage would be called upon to bear more load than is allowable for an indefinite actuator fatigue life. This is so while the aircraft flies at that part of the flight envelope at which high loads are developed.

A load monitor is provided which will detect conditions of actuator load unbalance and trip an indicator to record the event. The load monitor uses the delta-pressure sensors provided at the power stages of the swashplate servo actuator for stall flutter damping purposes.

If the load unbalance occurs because a single system is selected for checkout or startup purposes, the indicator is inhibited from operating.

The maintenance indicators are located on the stall damper control units. They are inspected on a scheduled basis. They may be reset by hand at the indicators themselves.

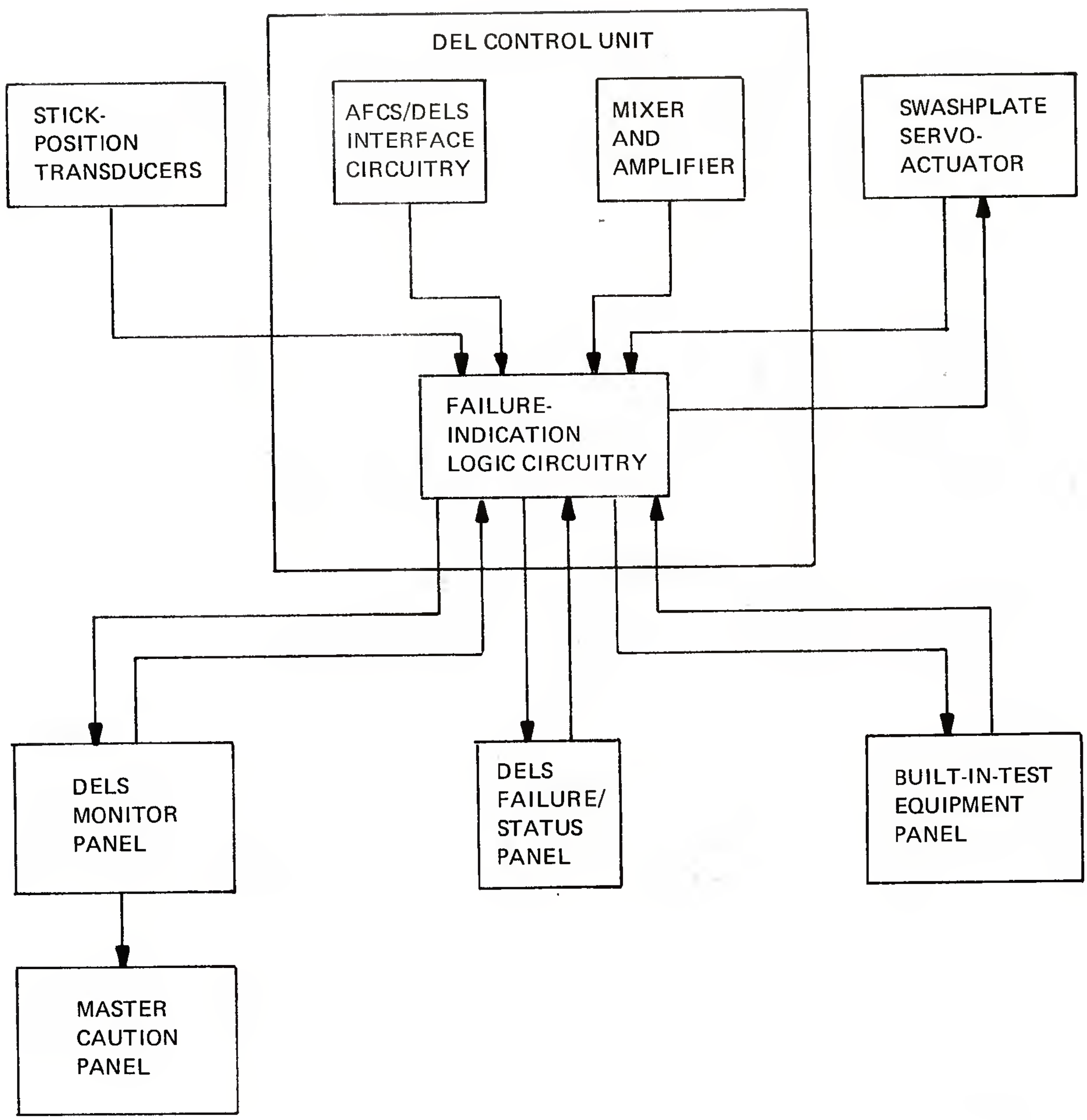


Figure 15. DELS Panels Interface Diagram

The load monitor is provided to allow a weight-economical actuator design. The need for it will be reviewed after the prototype aircraft has flown when flight-verification of load data is available.

FAULT ISOLATION - Interrogation circuits are provided in the DEL control unit for the purpose of identifying faults to LRU level. The facilities provided are designed to isolate faults with a 90-percent probability of correct diagnosis.

Manual fault isolation selector switches are installed on each DEL control unit together with meters which indicate the condition of the circuits under test on a"go/no go" basis.

The fault isolation facilities are separate and independent for each DELS channel.

The total fault isolation interrogation range provided by the selector switches is divided into zones to allow a more direct course to a fault to be followed.

Zone selection for a particular fault is based upon the failure annunciation made on the failure/status panel. The zones are servo loop, linkage, AFCS interface, stall damper and load monitor, and hydraulic interface.

Most failures will require the replacement of the DEL control unit, which is fortunate because this unit is most easily changed.

The fault isolation is not able to distinguish between certain SPT failures and problems in the aircraft mixing. A simulated SPT (stowed on the aircraft) is provided to make the diagnosis final and positive.

Because the change of a swashplate servo actuator is a large maintenance task, a special crossover cable is provided to check the diagnosis before removal. The crossover cable allows the cross-connection of channel elements to form a new element combination. Special precautions are taken to ensure that the aircraft is not allowed to fly with the crossover cable installed.

CHARACTERISTICS

Linkage Kinematics

The linkage ratios and travels are set at values shown in the table of Figure 16.

The travels are selected to give the desired control power in all axes and to avoid interference in the rotor system under adverse tolerance conditions.

The size of the AFCS limits were selected to give adequate range of control for the AFCS task and at the same time to be small enough to be useful as a limit of the input to the DELS under conditions of multiple failure occurring upstream.

Range is provided in the case of the longitudinal sequence signal, for a steady state signal variation adequate for generating a positive stick gradient.

Lateral and directional have range adequate for cancellation of the control offset that occurs in the basic aircraft with variations in airspeed.

The differences which are apparent between the forward and aft linkage ratios are present to account for kinematic differences between the forward and aft rotor systems, some of which is related to the delta-3 hinge which is present on the forward rotor head only.

Ratios ($G_{1 \text{ to } 6}$) are provided to establish the desired control sensitivity in the axes. Ratios ($G_{F1 \text{ to } 9}$ & $G_{A1 \text{ to } 9}$) set the gains appropriately for the azimuth of the swashplate servo actuator being served.

AFCS limits ($L_{1 \text{ to } 6}$), as was mentioned earlier, are provided to limit the effects of an upstream multiple failure should such an event occur.

Linkage limits ($L_{7 \text{ to } 10}$) prevent the absorbtion of authority by one pair of axes, in the domain of others.

Lastly, limits (L_3) prevent swashplate servo actuator over-travel at specific extremes of combination of cockpit control travel. These limits are needed because travel is not available for the worst case of all combinations of control extreme.

The cockpit control ranges are set by adjustable mechanical stops on the cockpit controls themselves.

Accuracy

The most pressing requirement for accuracy in the DELS arises in the need for tracking between channels. The three channels must agree closely with one another if the transients occurring upon channel transfer are to be kept small. To this end, the steady state gain accuracy is held in the region of ±2 percent of the ± full scale.

Resolution is less than ±2 percent of ± full scale swashplate servo actuator travel and hysteresis is less than twice this value.

Crosscoupling from axis to axis is such that less than 2 percent of control is required for compensation.

DELS components are interchangeable. No adjustments are necessary to achieve the tolerances.

The tolerances apply over the service environmental conditions applicable to the equipment.

Response

The DELS response is measured in terms of the output from the swashplate servo actuators to any input command. Input command may arise from the pilot, the AFCS, or feedback from the rotor system.

Pilot input frequencies require a control system band pass to 2.5 Hz. The AFCS requires a band pass to 7 or 8 Hz, based upon criteria for roll attitude hold performance.

Feedback from the rotor system is present in the form of alternating loads impressed upon the swashplate servo actuator. 4/rev loads are sensed by delta-pressure transducers and provide feedback signals to the servo summing point for stall flutter damping. These 4/rev loads represent a frequency of 10.4 Hz.

The servo loop response is similar to an ideal second order system with a corner frequency of 7.5Hz and a damping ratio of 0.6. This is based upon the AFCS flying qualities criteria. Although the frequency of operation of stall flutter damping is at a higher frequency (10.4 Hz), its needs are satisfied by simple signal compensation.

The velocity limit of the swashplate servo actuator is 6 in./sec at design load. This is adequate for maneuvers at high speed flight.

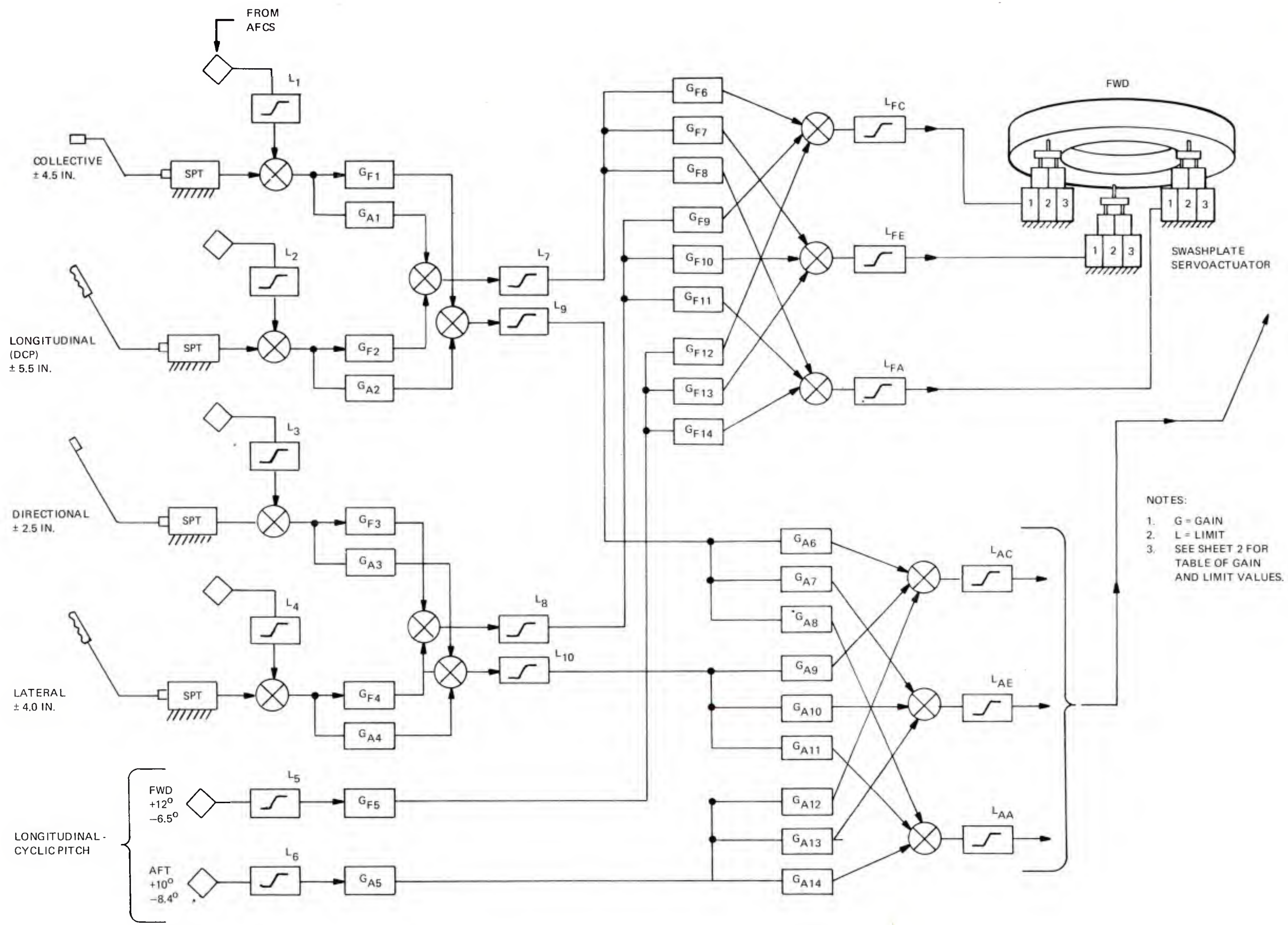


Figure 16. DELS Kinematics (Sheet 1 of 3)

TABLE OF GAINS AND LIMITS

GAIN VALUES			
G_{F1}	= 0.659	G_{A1}	= 0.643
G_{F2}	= 0.260	G_{A2}	= 0.205
G_{F3}	= 0.844	G_{A3}	= 0.990
G_{F4}	= 0.352	G_{A4}	= 0.405
G_{F5}	= 0.176	G_{A5}	= 0.225
G_{F6}	= 1.000	G_{A6}	= 1.000
G_{F7}	= 1.000	G_{A7}	= 1.000
G_{F8}	= 1.000	G_{A8}	= 1.000
G_{F9}	= 0.017	G_{A9}	= 0.259
G_{F10}	= 0.799	G_{A10}	= 0.602
G_{F11}	= 0.996	G_{A11}	= 0.999
G_{F12}	= 0.999	G_{F12}	= 0.996
G_{F13}	= 0.602	G_{A13}	= 0.799
G_{F14}	= 0.259	G_{A14}	= 0.017

LIMIT VALUES		
L_1 = L_2 = L_3 = L_4 = L_5 = L_6 =	See Sheet 3	INCHES OF EQUIV COCKPIT CONTROL
L_7	= + 4.000 − 4.390	INCHES OF EQUIV SWASHPLATE SERVOACTUATOR
L_8	= ± 2.830	
L_9	= + 3.642 − 4.013	
L_{10}	= ± 3.310	
L_{FA}	= + 6.810 − 7.300	
L_{FC}	= + 5.330 − 5.200	
L_{FE}	= + 7.040 − 7.230	
L_{AA}	= + 6.430 − 6.840	
L_{AC}	= + 6.040 − 6.350	
L_{AE}	= + 6.950 − 7.020	

Figure 16. DELS Kinematics (Sheet 2 of 3)

TABLE OF AFCS INTERFACE LIMITS

AXIS	HIGH-VEL LIMIT (AH)	LOW-VEL LIMIT (AL)	INPUT-SIGNAL RANGE ($A_{IN.}$)	LOW-VEL LIMIT RATE
	UNITS OF EQUIVALENT COCKPIT CONTROL			
L_1, COLLECTIVE	± 1.0 IN.	0	± 1.5 IN.	
L_2, LONGITUDINAL (DCP)	± 1.0 IN.	± 2.5 IN.	± 4.0 IN.	0.5 IN./SEC
L_4, LATERAL CYCLIC	± 0.75 IN.	L 1.70 IN. R 0.5 IN.	± 2.5 IN.	0.4 IN./SEC
L_3, DIFFERENTIAL LATERAL CYCLIC	± 0.66 IN.	L 1.60 IN. R 0.8 IN.	± 2.0 IN.	0.2 IN./SEC
L_5, LONG. CYCLIC CYCLIC (LCP) — FWD	± 4^o AUTO LCP ONLY	+ 12^o − 6.5^o	+ 12^o − 6.5^o	1^o/SEC
(DEGREES L_6 OF BLADE) — AFT	± 4^o	+ 10^o − 8.4^o	+ 10^o − 8.4^o	1^o/SEC

Figure 16. DELS Kinematics (Sheet 3 of 3)

Displacements of the swashplate servo actuator for stall flutter damping are limited to 1/8 inch (nominal) to take advantage of the available hydraulic flow at the power supply. Larger damping displacements would require special sizing of the power supply from flow and heat dissipation points of view.

The provisions made for stall flutter damping are the same as those made for the HLH prototype. They will be reviewed when the damper has been flight tested on the prototype aircraft.

A notch filter turned to a 1/rev frequency is provided in the collective axis to avoid pilot-induced oscillations at this frequency.

DELS EQUIPMENT

Six major building block components cooperate to form the DELS; they are:

	Number Per Aircraft
• DEL Control Unit	3
• Stall Damper Control Unit	2
• DELS Monitor Panel	1
• DELS Failure/Status Panel	1
• DELS BITE Panel	1
• Swashplate Servo Actuator	6

Features of each component are discussed in the following paragraphs.

DEL Control Unit

The DEL control unit illustrated in Figure 17 is mounted into a tray for quick-disconnect purposes. It is located in the tray with dowel pins at the rear and is secured by self-locking thumb screws at the front.

Pull handles are provided for box removal and handling. They also protect the components on the front face of the box.

The control unit is hand mounted to aircraft structure.

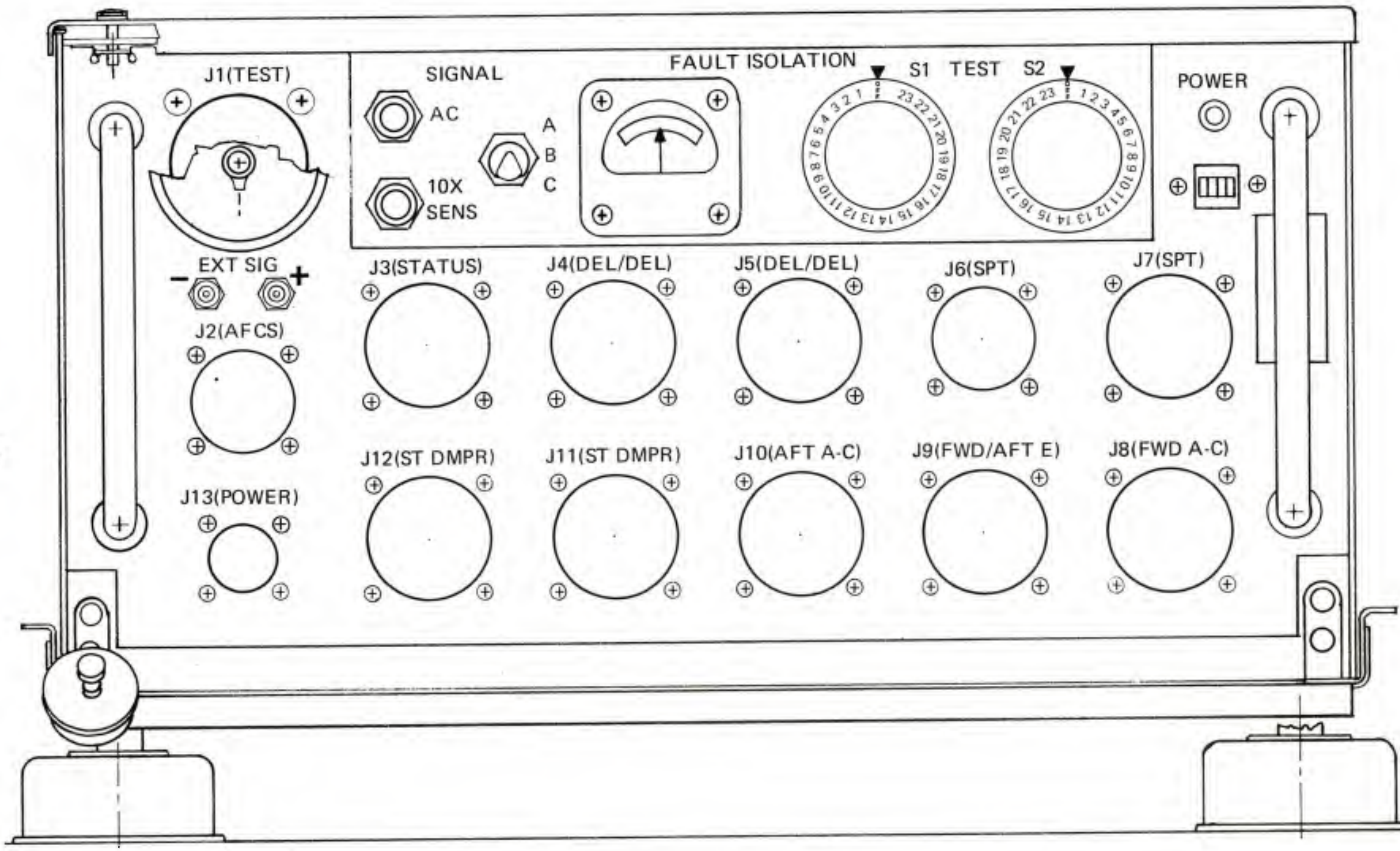


Figure 17. DEL Control Unit Front Face

Internally, the circuits are modularized onto plug-in cards. The power supplies are located on the rear box face which is finned for heat dissipation.

All connectors are located on the front face, one of which is a covered test connector. This is used for maintenance purposes.

The fault isolation facilities are located above the connectors.

A "power-on" lamp and a "time-elapsed" meter are also located on the front face of the box.

Stall Damper Control Unit

The stall damper control unit is tray mounted in a similar manner to the DEL control unit.

Plug-in card assemblies are used to accommodate the electronic components.

Electrical power is derived from the DEL control units and, therefore, the heat generated internally is negligible.

The electrical connectors are mounted on the front face of the box as indicated in Figure 18. One of these is a covered test connector which is used for maintenance purposes.

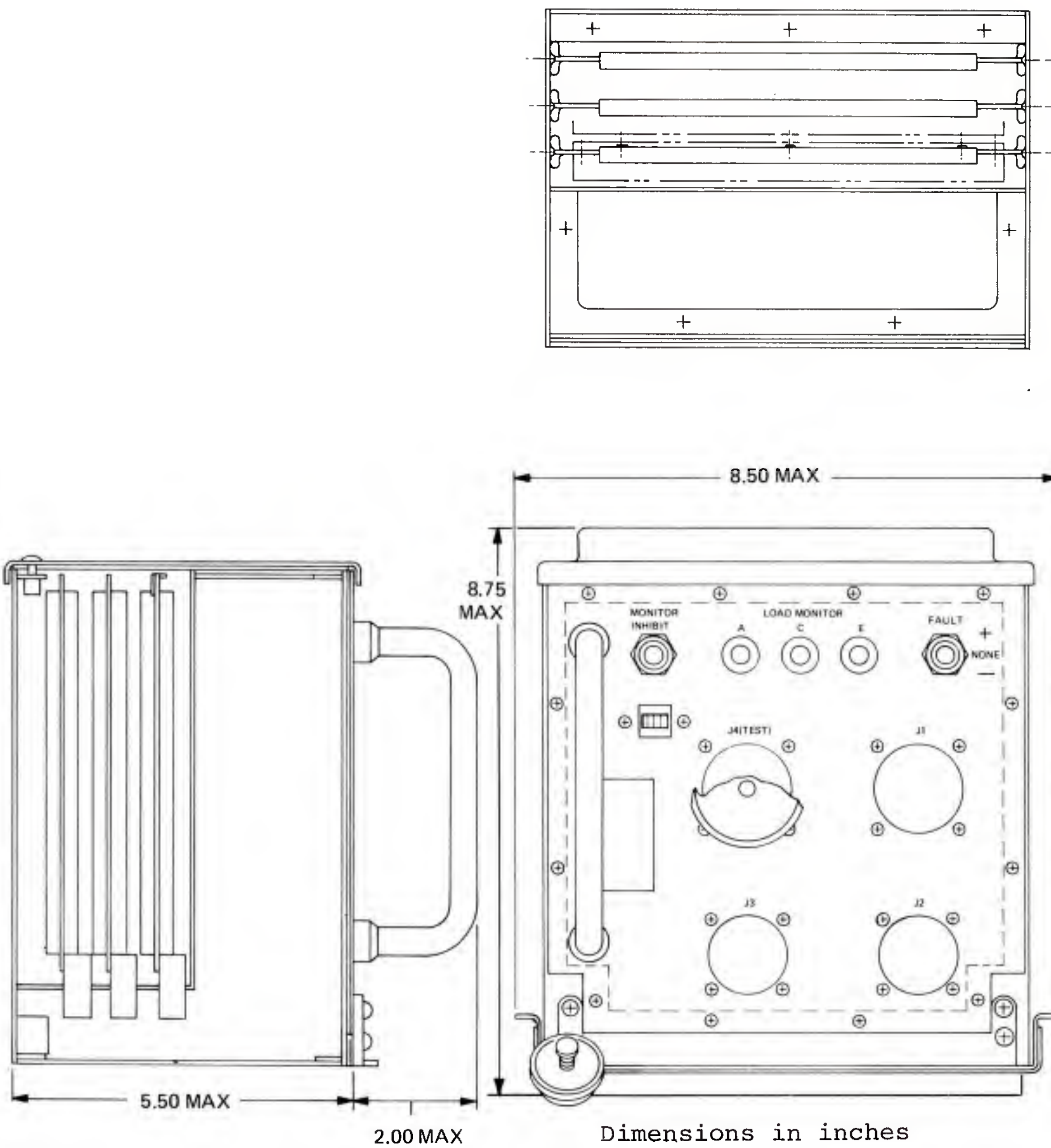
Three swashplate servo actuator load monitors are located above the connectors. One of the two stall damper units serves the actuators of the forward rotor head for this function and the other serves the aft.

The monitors are tripped by an electrical signal when an overload condition occurs. They may be reset manually at the box by maintenance personnel. Checkout facilities are provided on the box for the load monitor.

Swashplate Servo Actuator

Schematically, the swashplate servo actuator is shown in Figure 19; Figure 20 shows the physical arrangement. The power stage is duplex and the control stage is triplex. A 3000 psi hydraulic pressure source is used for the entire actuator.

The outputs of the three channels of the control stage are connected to a lever which represents a common control stage output force summing point. The lever drives the two



Dimensions in inches

Figure 18. Stall-Damper Unit

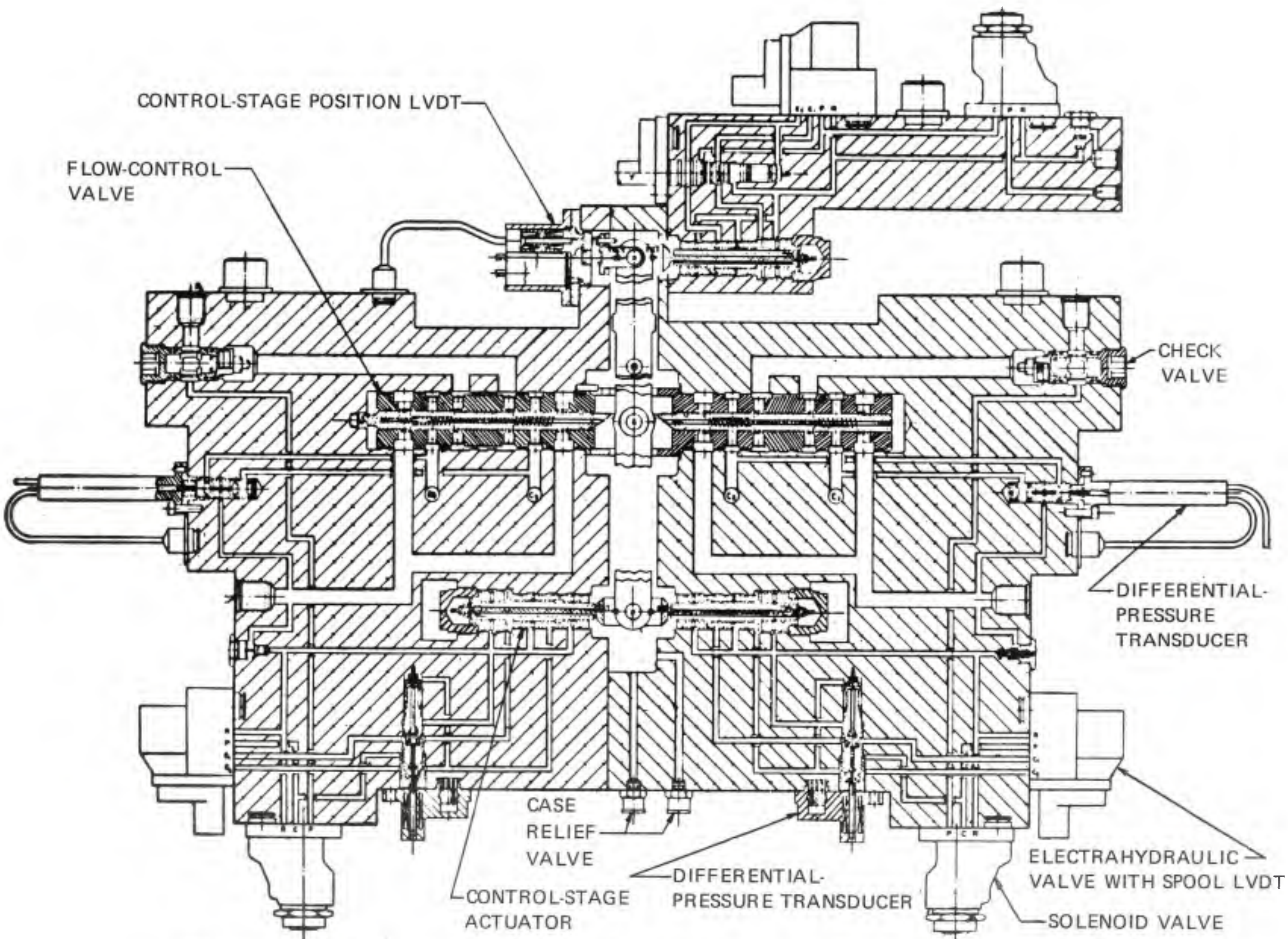


Figure 19. Swashplate Servoactuator Manifold Schematic

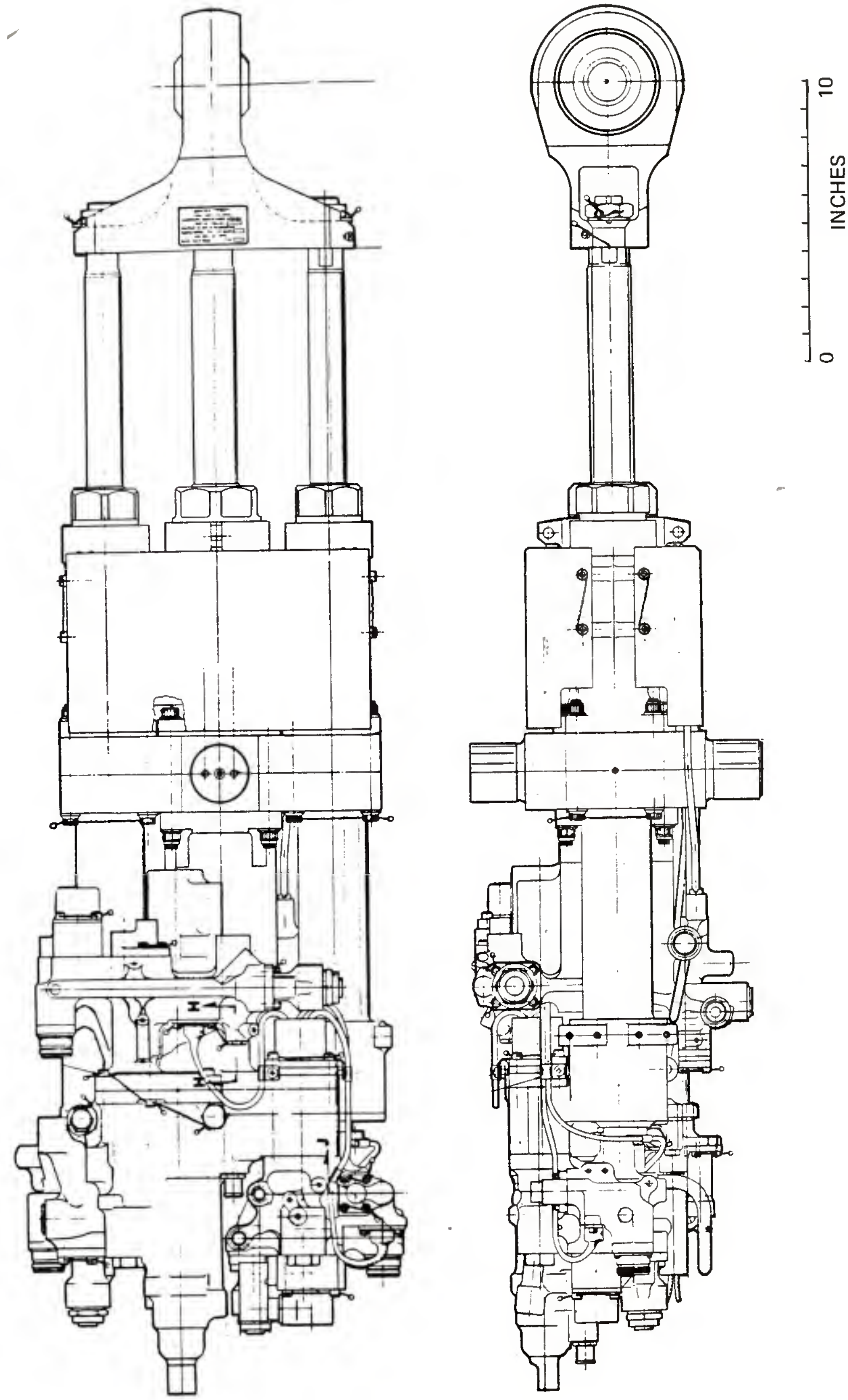


Figure 20. Swashplate Servoactuator

flow control valves of the duplex power stage through a mechanical advantage ratio of 2.4.

Leakage is controlled by elastomeric seals, rather than lapped fits, to reduce the chances of component binding. This does increase frictional forces but the penalty is considered to be worthwhile.

Jam-proof power stage valves are used to improve reliability further.

The components of each channel are mounted on three separate manifolds for system separation and resistance to crack propagation.

Control Stage

Three LVDTs representing control stage position feedback are attached to one common point of the lever. A common attachment point is used to limit tracking errors under conditions of varying temperature.

Two-stage electrohydraulic servo valves are used for flow control to each channel piston. The second-stage spools drive LVDTs which are used for detection of those valve failures which result in a lack of correspondence of the valve input/output.

The delta-pressure sensors, which are used for making the on-line channels compliant, are spring loaded so that they serve to bypass the pistons when shut down. These same sensors, in the bypass position, generate the information needed to indicate loss of hydraulic pressure at the actuator.

A single solenoid engage valve is used for each channel. It is of the coin type.

Power Stage

Three in-plane pistons are used in the power stage. The center belongs to system two and the outer two for system one. By this means, a balanced force output to the swashplate is achieved when operating on any single system.

Three (one per control stage channel) full-actuator-stroke position LVDTs provide electrical signals to close the outer actuator position loop. These are accommodated inside the actuator piston rods.

A pair of delta-pressure transducers sense pressure difference across the pistons of each system for use in the stall flutter damping loops and for actuator load monitoring. The sensors are used in pairs for failure detection purposes.

A check valve in the hydraulic pressure path is present to prevent actuator retraction from transient overloads. A check valve is inserted in the return line to isolate possible control stage leaks following a hydraulic power source failure.

The attachment of the swashplate servo actuator to its support is by means of a gimbal bearing which allows the actuator freedom to align itself with the locus of the attachment to the swashplate.

Titanium is used for the trunion, gimbal, and rod end assembly for weight saving purposes.

The rod end assembly is of single load path design. It is damage tolerant in that it has been designed with conservative stress margins. The rod end assembly bearing is a Dacron lined, fracture type which also operates at low stress levels for high wear resistance.

The swashplate servo actuator is designed to have a fatigue life of at least 3600 hours. Load carrying capability is sized to meet the following criteria:

- At V_H, with one failed system of a duplex actuator, the stall load of the remaining simplex portion shall be greater than the imposed peak load at 1.0g flight conditions.

- For 1.5g maneuvers at V_H, the stall load of a duplex actuator shall be greater than the imposed peak load. Also, the stall load of one simplex portion shall be greater than the imposed steady load.

- For demonstration maneuvers at 2.5g and V_H, the stall load of a duplex actuator shall be greater than the imposed steady load. Also, the peak load cylinder pressure shall not exceed the limit proof pressure of 4500 psi.

DELS Monitor Panel

The purpose of the DELS monitor panel is to provide a means by which the pilot may reset a failed DELS channel. A failed channel is indicated by an illuminated push-button switch, the operation of which will reset the failed channel if conditions are acceptable.

The panel, shown as Figure 21, also contains a guarded switch which allows the DELS BITE circuits to be armed.

DELS Failure Status Panel

This panel is mounted in a convenient location for maintenance purposes.

Three columns of red light-emitting diodes (LED) are panel-mounted (Figure 22) to indicate the locations of failures in the three channels of the system.

Additional green indicators are provided at each column to indicate which of the swashplate servo actuators are in the "active" (or master) status.

All LEDs on the panel are checked by a push button test switch. Failure indicators are latched on so as to store the information until cancelled by the panel reset.

DELS BITE Panel

Maintenance checkout of the DELS is performed by the operation of this panel (Figure 23).

When BITE is armed at the DELS monitor panel (Figure 21), the "ARMED" light on the BITE panel is illuminated.

DELS channel 1 is tested by rotating the test select switch from"OFF"to "1" and then pushing the "test initiate" switch. The BITE then automatically runs through a series of tests and stops when the tests are completed.

A row of LEDs at the top of the panel indicate the current test number in binary form. Should channel 1 fail to pass the test, a light in the lower portion of the "initiate" button will indicate the failure and the failed test will be indicated on the binary LED display. A light in the upper portion of the "initiate" button is illuminated while the test is in progress.

Channels 2 and 3 are tested in a similar manner.

The DELS is checked for system tracking errors when the panel test select switch is at CONT. In this test the cockpit flight controls are boxed to exercise the system and the system is monitored for failure trips.

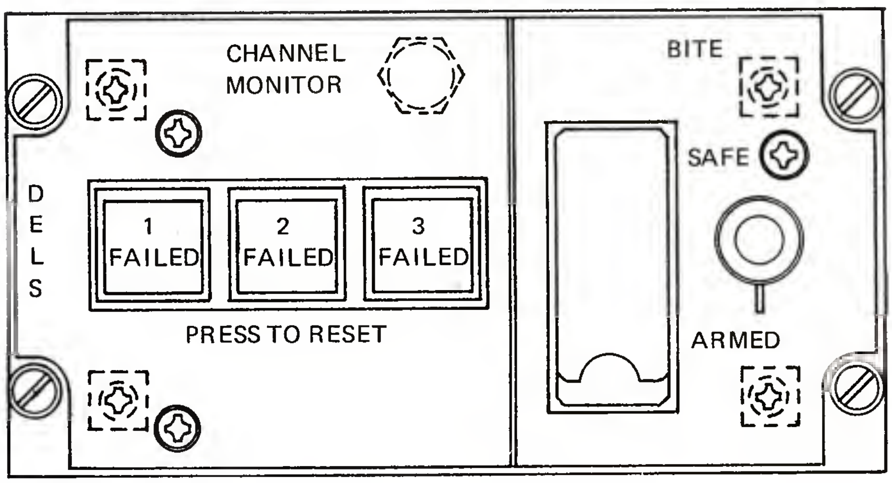


Figure 21. DELS Monitor Panel

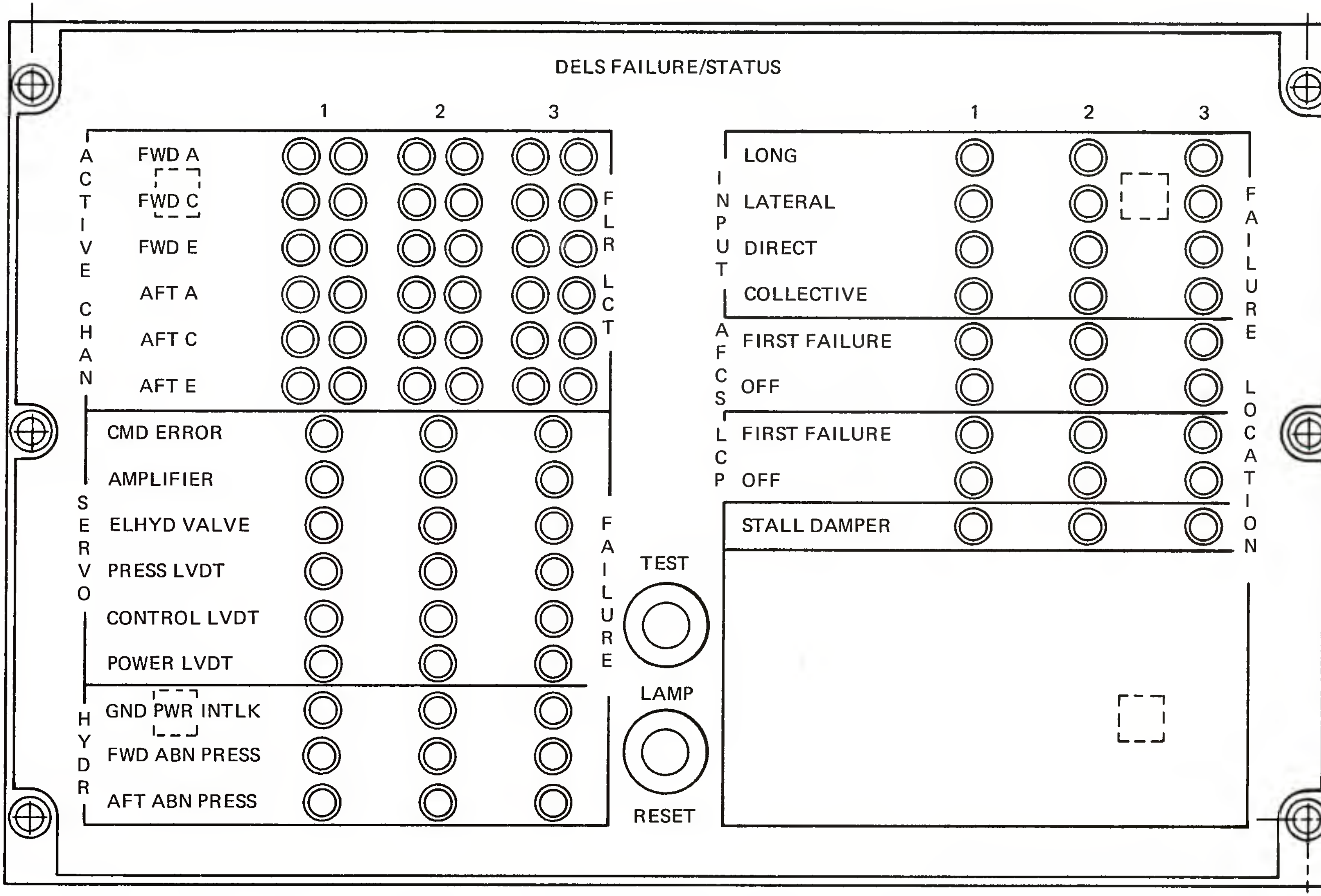


Figure 22. DELS Failure/Status Panel

The last position on the test select switch is for checking the stall damper function.

A lamp test button is provided.

The entire system is checked by this means in about 4 minutes.

DELS BITE panel is illustrated in Figure 23.

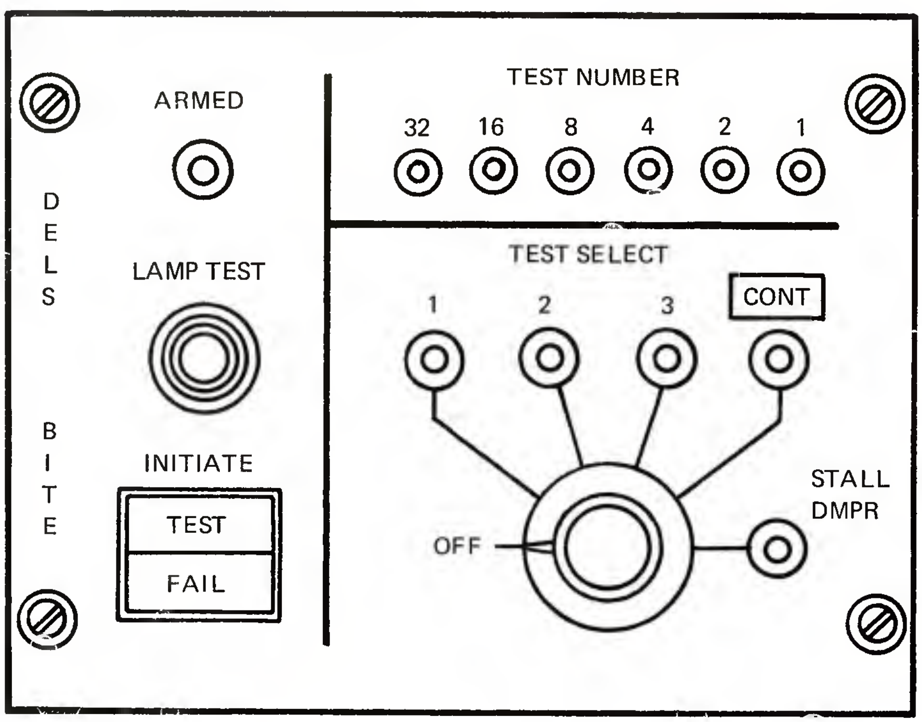


Figure 23. DELS BITE Panel

COCKPIT CONTROL SYSTEM (CCS)

DESIGN APPROACH

Improved conventional cockpit controls were recommended for the HLH in the ATC Task 1, Part 1 Summary Report (Reference 1). These were found to be best suited to the range of selectable AFCS modes. They were very satisfactory in the ATC flight testing. Pilot interface characteristics, Survivability/Vulnerability, and weight were considered to be of prime importance to the design of the cockpit controls. In the interest of control fidelity, the cockpit controls are designed for low hysteresis and friction.

Particular linkage elements are sized to create a tolerance to hits from 12.7mm ballistic missiles. Others are redundant so that loss of the element does not cause loss of function.

Shear pins are provided to allow jams at critical points to be cleared by overpowering by the pilot.

The stick position transducers are dispersed to reduce vulnerability.

The CCDAs which drive the controls for autopilot type functions are mechanized with a failsafe characteristic to satisfy the needs of IFR operations.

DESCRIPTION

The cockpit control system translates pilot command motions into proportional electrical signals at the outputs of the stick position transducers. The controls are dual (pilot and copilot) and operate in vertical, longitudinal, lateral, and directional.

The CCS is comprised of five major parts, cockpit control linkages, stick position transducers, force feel capsules, cockpit control driver actuators (CCDA) and servoelectronics, and dampers. These parts are arranged as depicted in the diagram presented as Figure 24.

Cockpit Control Linkage

Figure 25 is a general arrangement drawing of the cockpit controls. It shows that the main members in each axis are torque tubes which are supported at three places such that operation is unaffected by loss of any one support. Large-

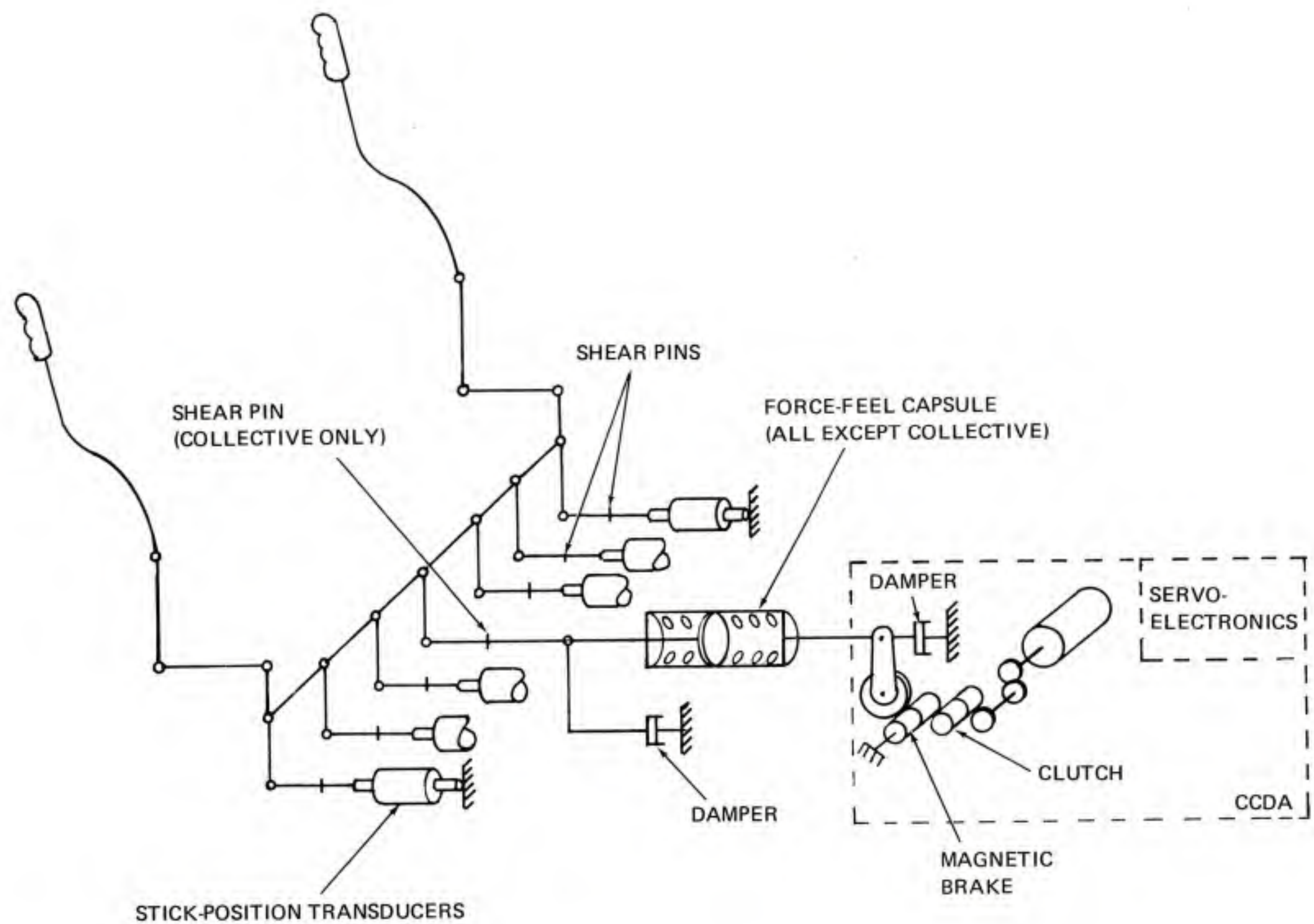


Figure 24. Diagram of Cockpit Controls (Single Axis)

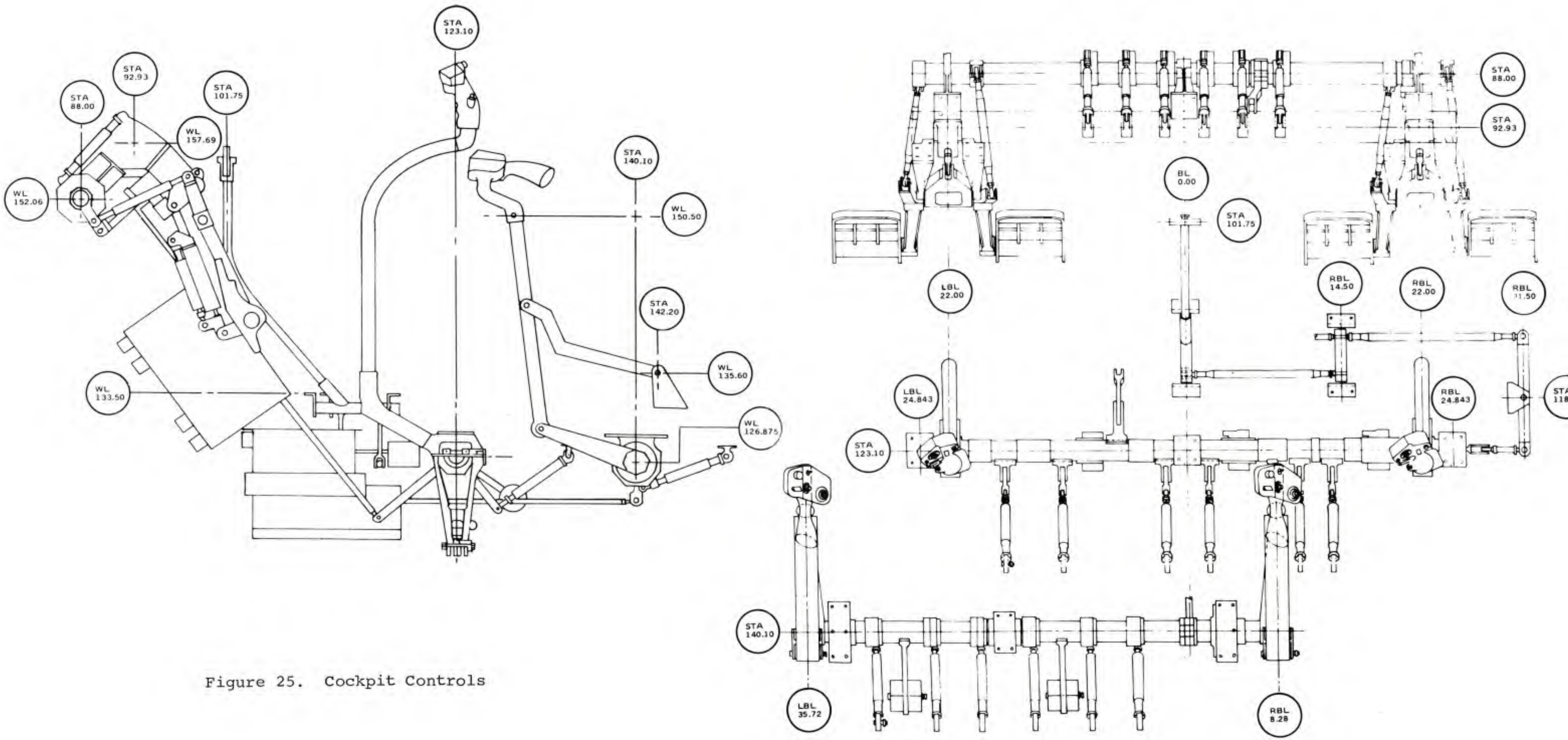


Figure 25. Cockpit Controls

diameter tubing is used to provide tolerance to damage from 12.7mm ballistic missiles.

Pilot and Copilot controllers are separately connected to the torque tubes. SPTs are dispersed and separately connected to the linkage. The opposite ends of the SPTs are separately connected to structure. These individual connections enhance the survivability/vulnerability characteristics.

Shear pins are present in the drive connections to the SPTs so that a jam occurring at any SPT may be cleared by the application of an overriding force by the pilot. Impedance bolts are used at linkage connections to ensure retention of the bolt in the event that a securing nut is lost.

Each axis' controls are mass balanced. Some of the mass balancing may be replaced by force balancing in the interests of weight saving. The degree that this may be pursued without incurring adverse control feel effects remains to be determined.

The control pedals are suspended (that is, pivoted above) to reduce obstruction to vision through the chin windows below. The pedals are adjustable for reach by an electrically operated mechanism and toe-operated wheel brakes are provided.

Adjustable mechanical stops are installed in each axis of control and these allow the full range of travel indicated in a later paragraph.

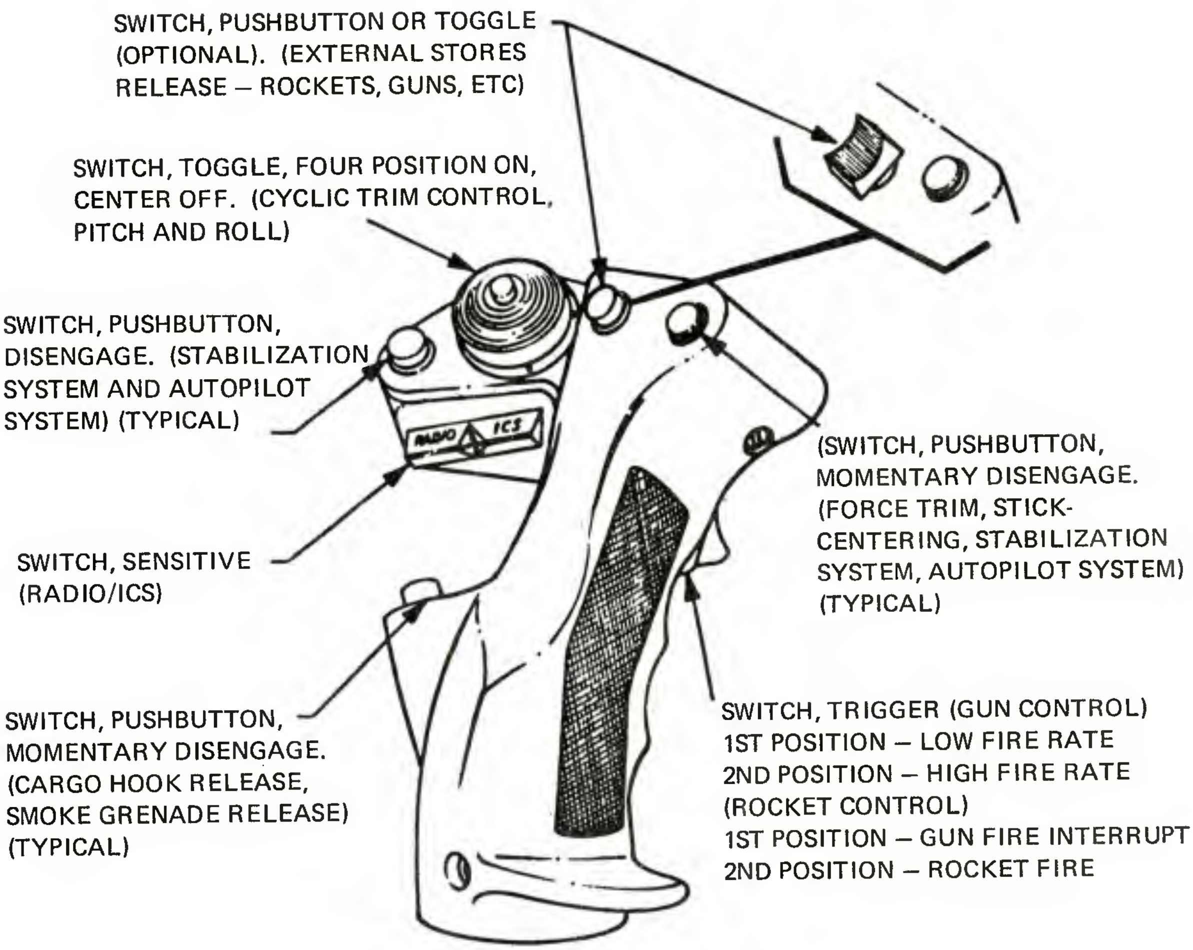
Facilities are provided for the controls to accept rigging pins which lock the cockpit controls at mid-travel position while the SPTs are adjusted for null.

Main bearings are rolling element type,to reduce friction.

Control Grips

The control grip for the longitudinal/lateral controller is illustrated in Figure 26. It conforms to Military Standard MS-87017(AV).

Figure 27 shows the grip for the collective controller. This grip is the result of a development by The Human Engineering Laboratory, Aberdeen Proving Ground, Maryland and is being established as a standard.



STANDARD ARRANGEMENT AND FUNCTIONS OF SWITCHES

NOTES:

1. FUNCTIONS DIFFERENT THAN THOSE SPECIFIED ABOVE SHALL BE SUBMITTED TO THE PREPARING ACTIVITY FOR APPROVAL.
2. GRIP DESIGN AND COMPONENT INSTALLATION SHALL BE IN ACCORDANCE WITH MIL-G-58087 (AV).
3. INTERNATIONAL STANDARDIZATION: CERTAIN PROVISIONS OF THIS STANDARD ARE THE SUBJECT OF INTERNATIONAL STANDARDIZATION AGREEMENTS (ASCC AIR STD 10/15, LOCATION, ACTUATION AND SHAPE OF ALL AIRFRAME CONTROLS OTHER THAN PRIMARY FLYING CONTROLS AND ASCC AIR STD 10/22, SERVICES OPERABLE FROM STICK GRIP IN BOTH FIXED WING AND ROTARY WING AIRCRAFT). WHEN AMENDMENT, REVISION, OR CANCELLATION OF THIS STANDARD IS PROPOSED WHICH WILL AFFECT OR VIOLATE THE INTERNATIONAL AGREEMENT CONCERNED, THE PREPARING ACTIVITY WILL TAKE APPROPRIATE RECONCILIATION ACTION THROUGH INTERNATIONAL STANDARDIZATION CHANNELS, INCLUDING DEPARTMENTAL STANDARDIZATION OFFICES, IF REQUIRED.
4. REFERENCED DOCUMENTS SHALL BE OF THE ISSUE IN EFFECT ON DATE OF INVITATIONS FOR BID.

Figure 26. Cyclic Control Grip - From Military Standard MS-87017(AV)

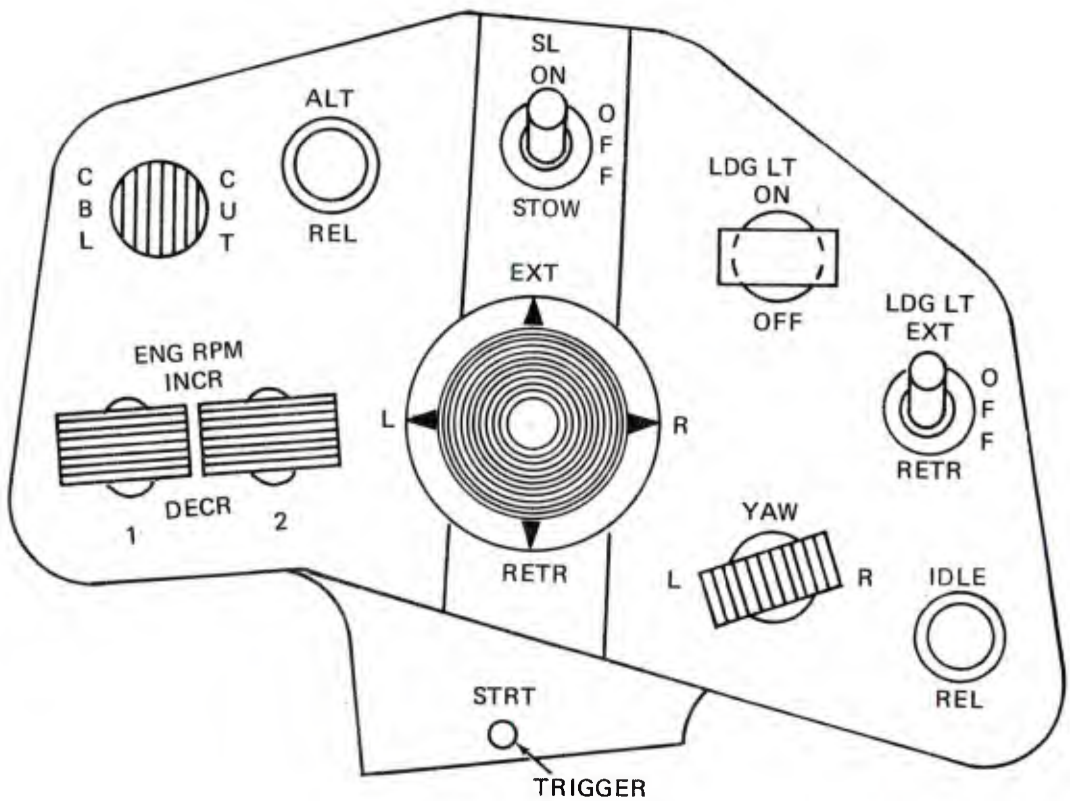


Figure 27. Type I Collective-Stick Control Developed for Standardization in Large Types of U.S. Army Helicopters

Stick Position Transducers

Stick position transducers of the LVDT type generate electrical signals proportional to cockpit control displacement. Totally, 24 are used (two per channel for three channels and four axes).

The transducers are illustrated in Figure 28. Each is protected by an enclosure which also serves to shield the windings magnetically.

Universal bearings are used at SPT attachments to allow automatic adjustment for alignment. Length adjustment is provided for the purpose of trimming the electrical null when the SPT is first installed.

Force-Feel Capsule and Damper

Figure 29 shows a conventional force-feel capsule as is used with the longitudinal, lateral, and directional controllers. The parts of the capsules for each are common with the exception of the springs which are particular to the force-feel characteristics desired for each axis.

The collective controller is connected directly to a slip clutch in the CCDA to provide a force breakout without a gradient.

Provision is made for a standard off-the-shelf damper in each axis. The necessity and settings for these will be determined on the actual HLH flight test vehicle.

Cockpit Control Driver Actuator (CCDA)

The purpose of the CCDAs is to drive the cockpit controls in an autopilot manner from AFCS signals in four control axes. They drive the longitudinal, lateral, and directional controllers through the force feel capsules, and the collective controller by direct coupling. All may be overridden by the pilot; the collective by virtue of a slip clutch in the CCDA, the other axes by motion of the force feel capsules.

The CCDA is electromechanical and is shown in block diagram form in Figure 30. The output from the servo is transmitted through a clutch to the output lever. A magnetic brake secures the output lever when the servo is not operational.

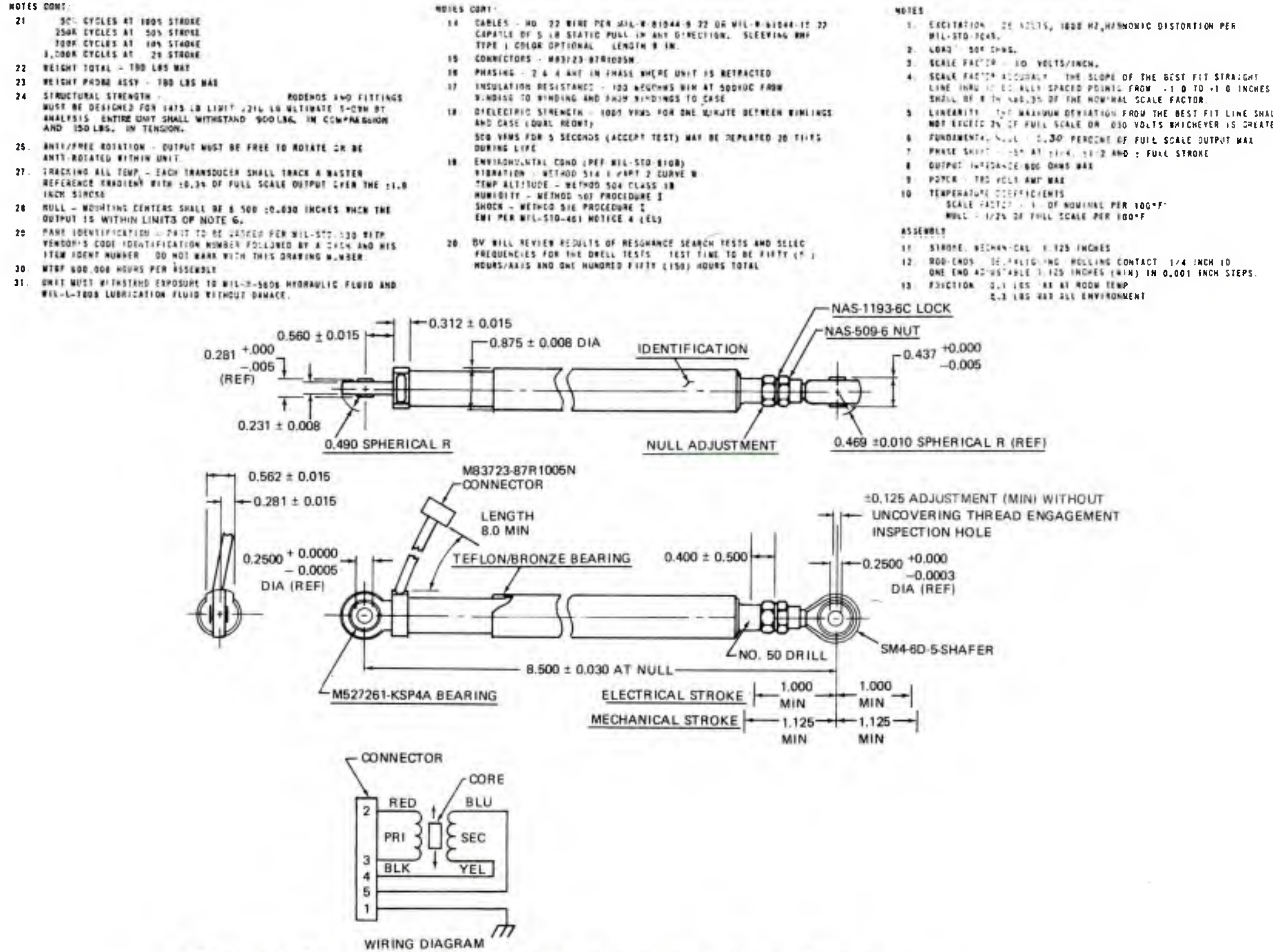


Figure 28. Control Stick Position Transducer

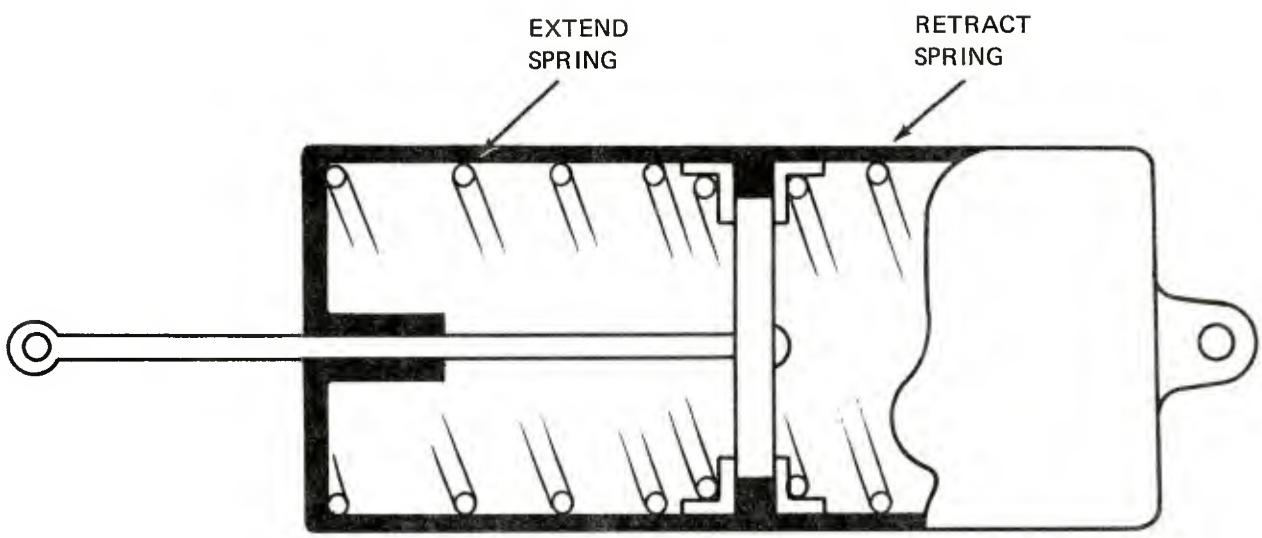


Figure 29. Typical Force-Feel Capsule

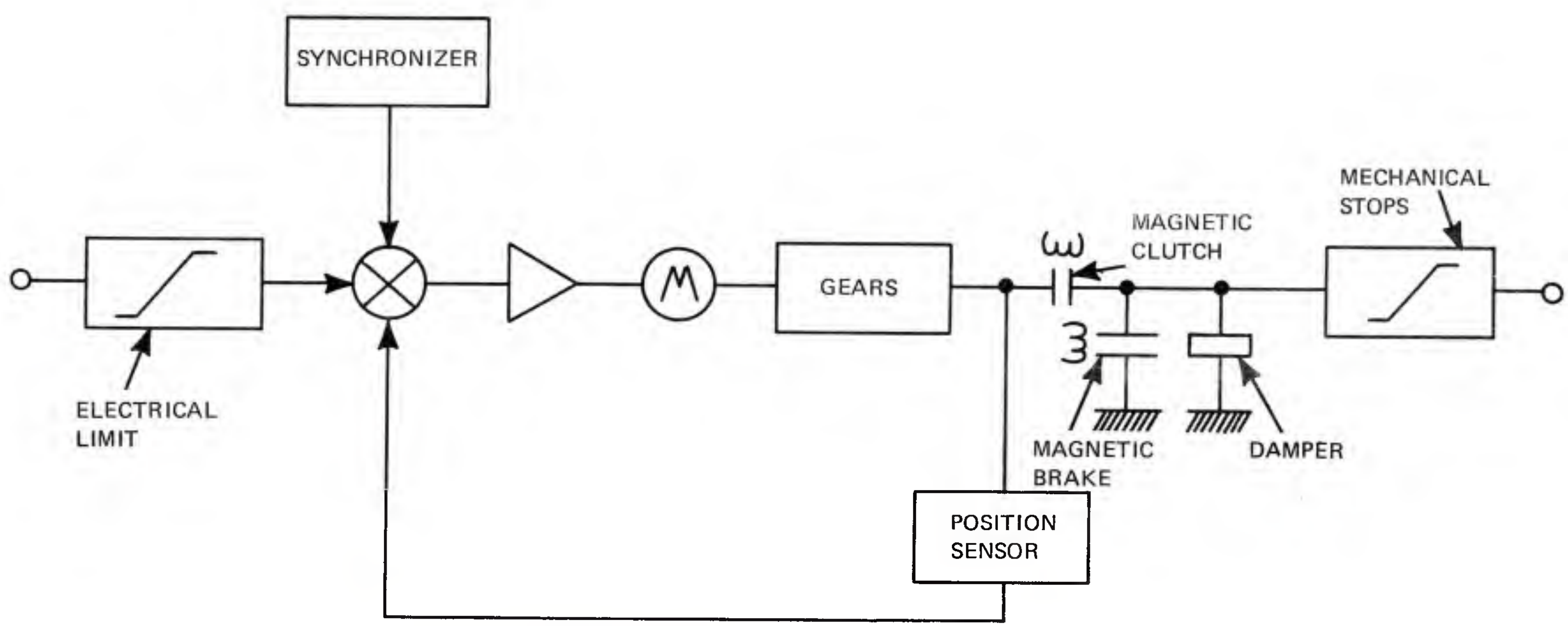


Figure 30. CCDA Servoloop Block Diagram

The output lever serves as a reaction point for the force-feel devices. The controls may be zero-force trimmed to any desired position by operation of trim switches on the controller grips.

The CCDA is self-monitored so that it is automatically shut down in the event of failure. The pilot is notified of the shutdown and may reset the system if the failure is cleared. The servo electronics are contained within the CCDA package.

BITE facilities are provided to allow the system to be routinely checked without special support equipment. This ground check ensures that the system is in proper working condition and that the failure detection circuits are effective. BITE circuits are inhibited from operation in flight by interlocks.

CHARACTERISTICS

Control Travels

Full travel in each axis for the cockpit controls is:

Vertical	$\pm 4.5"$
Longitudinal (DCP)	$\pm 5.5"$
Lateral	$\pm 4.0"$
Directional	$\pm 2.5"$

The design permits the directional travel to be increased to $\pm 3.0"$ to allow an option for a lower sensitivity. Full travel motions at the SPT are $\pm 1.0"$, nominally.

Control Feel Characteristics

Force breakouts and gradients in each axis are set at values which are a selected compromise between the preferred values for high-speed maneuvering and for precise helicopter positioning in hover. The values are tabulated as follows:

CONTROLLER	BREAKOUT (LB)	GRADIENT (LB/IN)
Collective	3.5	0
Longitudinal (DCP)	1.5	1.5
Lateral Cyclic	1.0	1.0
Directional (Pedals)	7.5	4.5

Control velocity damping is adjustable, but is set to give a nominal damping ratio of 0.7. CCDA bandwidth, 4-5 rad/SEC. CCDA velocity limit:

	in. cockpit control/second
Longitudinal	1.2
Lateral	0.9
Directional	0.55
Vertical	1.0

Human Factors

The location and travels of the cockpit controls are designed to satisfy the general requirements of MIL-STD-1333 "Aircrew Station Geometry" and MS-33575 "Basic Dimensions - Helicopter Cockpit". Exceptions to the dimensions indicated in these standards occur in two instances. The pedal travel is ±2.5" instead of ±3.25" and the collective controller travel is 7.7" instead of 9.5". The resulting control location dimensions are indicated in Figure 31.

The sensitivity associated with ±2.5" of pedal travel was deemed to be desireable for this type of helicopter by evaluating pilots in recent flight test and simulation programs. Provisions are retained in the design to allow the pedal travels to be increased to ±3" should this be considered desireable later.

Because the collective controller has adequate range at the selected sensitivity, no problems are expected to result from the travel being smaller than the amount specified in the standard.

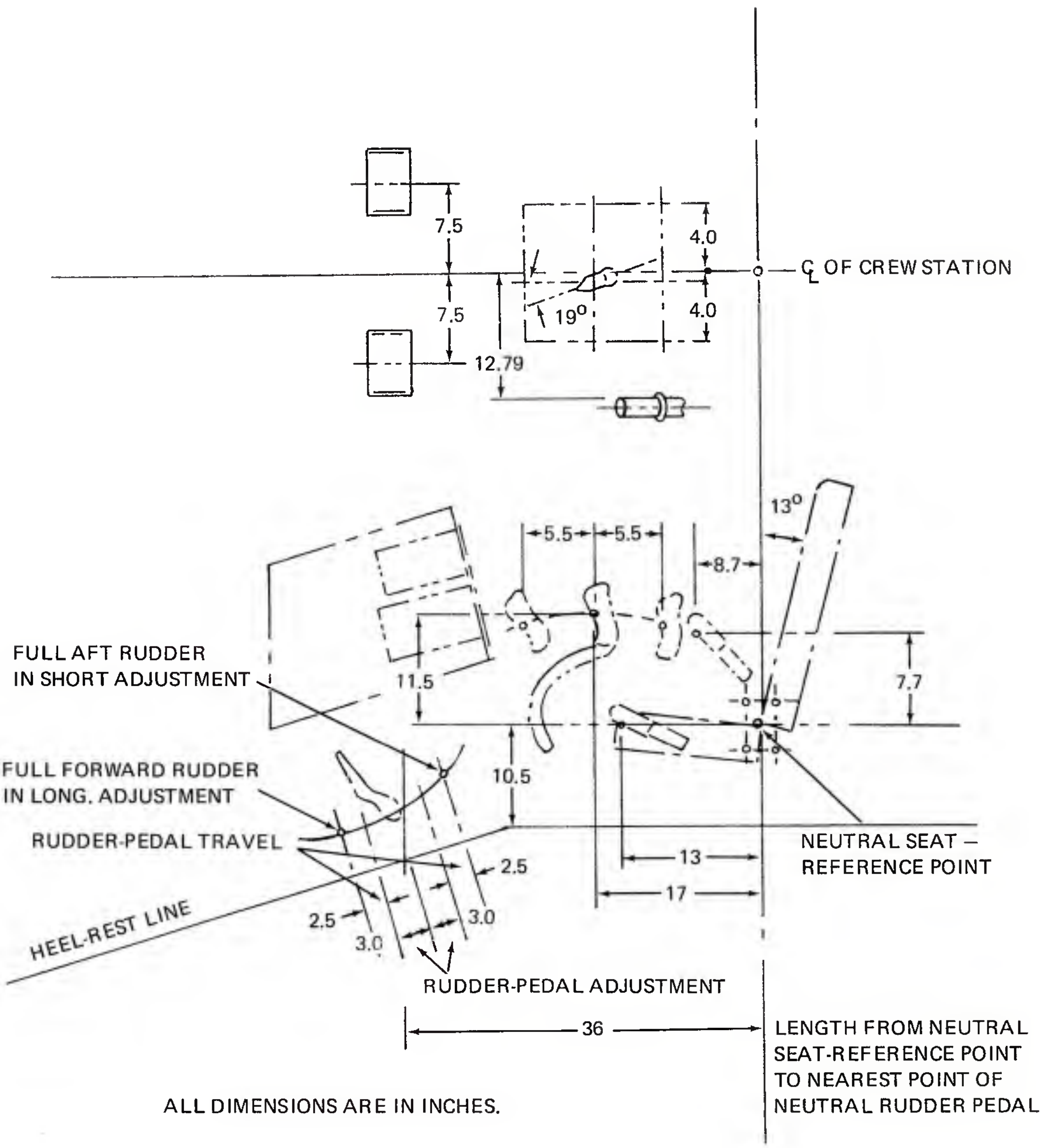


Figure 31. HLH Flight-Control Dimensions

AUTOMATIC FLIGHT CONTROL SYSTEM

MISSION

The principal HLH mission demands the efficient acquisition, transportation, and deposition of container cargo in VFR or IFR weather, day or night. Mission payloads, varying in weight up to 35 tons, typically consist of large bulky cargo modules slung beneath the helicopter. The aircraft has to be capable of being confidently maneuvered into confined areas for the accurate transfer of load. To facilitate this kind of operation, the HLH is given a special rear-facing crew station, occupied by a Load Controlling Crewman (LCC).

The LCC has a clear view of the load and has separate aircraft controls designed for precise maneuvering and trim hold. These load operations, requiring the aircraft to be maneuvered with respect to ground obstacles at destinations and departure locations, require the aircraft to be maneuvered and stabilized with respect to ground velocities in the low speed region. Forward flight on the other hand requires air mass references.

One of the foremost objectives of the flight controls portion of the ATC program was to define the type of handling qualities needed for the HLH mission and to outline the manner in which these should be achieved in the production HLH.

The handling qualities recommendations made in the following pages are based upon the results of the ATC program, details of which are given in Volume III.

RECOMMENDED PERFORMANCE CHARACTERISTICS

Basic SCAS - Stability

In the basic SCAS mode, the aircraft is stabilized with respect to the parameters given in Table 2. The advantage of ground speed stability in the longitudinal and lateral axes in the low speed region is that the pilot workload is less in gusty winds when maintaining a ground track or hover.

TABLE 2. RECOMMENDED STABILITY CHARACTERISTICS

AXIS	HOVER AND LOW SPEED FLIGHT ($<$45 kts)	FORWARD FLIGHT ($>$45 kts)
Longitudinal	Ground Speed Hold	Airspeed Hold
Lateral	Ground Speed Hold	Bank Angle Hold
Vertical	----	----
Directional	Heading Hold	Heading Hold (for zero turn command) Sideslip for banked turns

More conventional airmass references are best suited to forward flight conditions where detailed maneuvering with respect to the ground is no longer required.

An automatic transient-free switch is used to translate between the ground speed and airspeed references. The mechanization is described in Volume III.

Basic SCAS - Pilot Control Responses

Basic SCAS control response will be discussed in five areas; the first four relate to the pilot's use of a groundspeed/airspeed select capability, and the fifth will relate to the response characteristics for LCC. The four positions of the groundspeed/airspeed select are:

NORMAL-----------Automatic transition from one to the other at 45 knots airspeed.

AIRSPEED---------Airspeed reference for the complete envelope except below 40 knots. Because the airspeed signal deteriorates at about 40 knots, the software will hold the value constant below 40.

GROUNDSPEED------Groundspeed reference for the complete envelope for the longitudinal axis. In the lateral axis, the response is to groundspeed below 45 knots becoming bank angle and turn coordination above.

OFF--------------No velocity response

Normal Control Response, Automatic/Groundspeed Selected

The normal control response characteristics are shown in Table 3. The responses to beep trim are similar, excepting that the response to lateral beep trim in the forward flight condition is simply "bank angle".

TABLE 3. RECOMMENDED CONTROL RESPONSE CHARACTERISTICS

AXIS	HOVER AND LOW SPEED FLIGHT (<45 kts)	FORWARD FLIGHT (>45 kts)
Longitudinal	Longitudinal Groundspeed	Airspeed
Lateral	Lateral Groundspeed	Bank angle for less than 10°. Roll rate for greater than 10°. Automatic pedal fixed turn coord. for all bank angle commands.
Directional	Heading rate	Sideslip
Vertical	Altitude rate	Altitude rate

Control Response, Airspeed Reference Selected

Table 4 shows the longitudinal and lateral control responses when airspeed velocity reference is selected. Below 45 knots, the longitudinal response is pitch attitude. This is necessary because the airspeed signal deteriorates below approximately 40 knots. Software holds the airspeed value constant below that speed. At low speeds, the lateral response is bank angle and roll rate as shown.

Above 45 knots, the longitudinal response is airspeed. In lateral, a control input commands bank angle initially and then roll rate at larger bank angles than 10 degrees.

TABLE 4. RECOMMENDED CONTROL RESPONSE CHARACTERISTICS

	AXIS	VEOLCITY REFERENCE SELECT		
		AIRSPEED	GROUNDSPEED	OFF
		CONTROL INPUT	CONTROL INPUT	CONTROL INPUT
HOVER AND LOW SPEED	Longitudinal	Pitch Attitude	Pitch Attitude	Pitch Attitude
	Lateral	Bank angle for angles $<10^\circ$ Roll rate for angles $>10^\circ$	Lateral Groundspeed	Bank angle for angles $<10^\circ$ Roll rate for angles $>10^\circ$
FORWARD FLIGHT	Longitudinal	Longitudinal Airspeed	Longitudinal Groundspeed	Pitch Attitude
	Lateral	Bank angle for angles $<10^\circ$. Roll rate for angles $>10^\circ$. Automatic pedal fixed turn coordination for all bank angle commands.		

Control Response, Groundspeed Reference Selected

Below 45 knots, as shown in Table 4, the longitudinal and lateral control inputs command groundspeed. Above 45 knots, the longitudinal axis response remains groundspeed. The lateral axis crosses over to bank angle and roll rate with turn coordination for all bank angle commands.

Control Response, No Velocity Reference

The system provides the capability for no velocity reference. This selection may be made for a mission task such as towing. As shown in Table 4, longitudinal response is pitch attitude; lateral response is bank angle and roll rate with automatic turn coordination above 45 knots.

SELECTABLE MODES

Several selectable modes are incorporated into the AFCS to provide suitable characteristics for particular mission tasks. These modes are:

- Altitude hold
- Hover (position) hold
- Hover (velocity) hold
- Load stabilization
- Automatic approach to hover

Some additional comment is given in this section relative to modes evaluated in the ATC program which are not recommended for the production aircraft. Volume III gives detail descriptions of each of these selectable modes.

Stability Features - Selectable Modes

Stability features of the selectable modes are listed in Table 5 and discussed in later paragraphs.

TABLE 5. STABILITY FEATURES - SELECTABLE MODES

AXIS	ALTITUDE HOLD	HOVER HOLD	
		POSITION	VELOCITY
Longitudinal		Longitudinal Position Hold	Longitudinal Vertical Velocity Hold
Lateral		Lateral Position Hold	Lateral Vertical Velocity Hold
Vertical	Altitude Hold Baro or Radar	Vertical Position Hold	Vertical Position Hold Radar
Directional		Heading Hold	Heading Hold

Altitude Hold

Both absolute altitude hold and barometric altitude hold capabilities are recommended for the HLH. It is recommended that the pilot be provided with four-way selection: absolute, barometric, automatic, or OFF.

In the automatic position, the altitude reference is pressure altitude above 200 feet absolute and is absolute below 200 feet. System switching is automatic and transient free. This feature was evaluated in the ATC flight program and is recommended.

It is further recommended that when the pilot has selected "automatic", that the absolute altitude hold be inhibited above 50 knots. This will prevent automatic altitude excursions resulting from terrain features. The recommendation was derived from pilot comment during ATC testing.

If the terrain or mission situation is such that the pilot desires absolute altitude hold regardless of forward speed, he selects "absolute".

Hover (position) Hold

This selectable mode is not recommended as a built-in feature of the production HLH because the need for it is restricted to gusty conditions. In calm air the normal hover hold mode is quite satisfactory.

The ATC program demonstrated the performance capability of a precision(position)hover sensor (see Volume III) but its use is not recommended because of the unfavorable impact of cost and weight,bearing in mind the low percentage of use in the mission.

A target-located cooperative device is recommended for those cases where the tight position hover hold would be advantageous. To this extent the hover position hold is recommended as an optional feature.

Hover (velocity) Hold

A hover hold capability which uses X and Y inertial velocities is recommended for the HLH. This type of hover hold is available to pilot and to load controlling crewman (LCC).

For the LCC high gain inertial velocity, loops were programmed for the ATC evaluations. Absolute measurements of position error showed a hold capability to 1.4 feet CEP in gusty air. It is recommended that this capability be provided for the HLH.

Load Stabilization

Three functions of load stabilization were evaluated in the ATC flight program; they were:

- pendular damping,
- over-the-load centering, and
- load position hold

Only pendular damping was recommended for the HLH from these evaluations for reasons stated in later paragraphs.

Other load stabilization programs employing active-arm pendants have recently been conducted with beneficial results. A review of the merits of the various approaches is recommended before a selection is made for the HLH. The load stabilization comments which appear in the next paragraphs relate to the ATC program findings only.

The test vehicle had some limitations in simulating the HLH. Whereas the latter will use cargo winches which can change cable length in flight simultaneously or individually, the test vehicle had to use fixed sling lengths for each test condition. Also, the radar altitude signal was disturbed by the load with slings 30 feet or longer. However, it is not believed that these limitations negate the merit of the recommendations given below.

Pendular damping - It is recommended that cable/load sensors be incorporated in the cargo winches for interface with the AFCS. Sensors should provide cable angle, cable length, and tension. Damping action is recommended in longitudinal, lateral, and directional modes.

Flight test results, Volume III, show that damping ratios between 20-percent and 30-percent critical were achieved with 30-foot slings. The damping improves the efficiency of load acquisition and discharge.

Over-the-Load Centering - This selectable mode is not recommended for the HLH. The LCC was capable of flying the aircraft over the load with ease. This feature is considered an unnecessary complication.

Load Position Hold - This selectable mode is not recommended for the HLH. Load position hold requires the precise aircraft position data from the precision hover sensor and cable angle and cable length data from the load stabilization sensors. A position change of the load is corrected by an aircraft position change in the opposite direction. Test data given in Volume III shows that such a system function is technically feasible, however, pilot evaluation was unfavorable. "Hands off", the ride is very uncomfortable and as previously stated, the placement of a load is a maneuvering task. When the pilot enters the loop he finds the system "fighting" his inputs; load stabilization worsens. The pilot performs load placement more efficiently with load position hold off, using only the pendular damping mode of load stabilization.

Recommended LCC Control Response

Hover hold responses to the load controlling crewman's controller are tabulated in Table 6. The ATC program provided a position beep response which used the precision hover sensor. By moving this controller momentarily out of detent when in precision hover, the LCC could command a position change of two inches. In keeping with the recommendation not to utilize a precision hover sensor as a built-in feature, it is recommended that this response not be provided in the HLH.

TABLE 6. LCC CONTROL RESPONSE

AXIS	CONTROL INPUT	POSITION BEEP
Longitudinal	Longitudinal Groundspeed ± 15 FT/SEC	Not Recommended
Lateral	Lateral Groundspeed ± 15 FT/SEC	
Directional	Heading Rate $\pm 8^{\circ}$/SEC	
Vertical	Vertical Rate ± 6 FT/SEC	

It is recommended that the nonlinear control sensitivity shaping be used. However, the maximum groundspeed demand for the load shuttle task should be increased. This must be done in conjunction with increased control stick travel in order to maintain sufficient control gradient sensitivity for efficient load acquisition and discharge.

Recommended Pilot Control Response, Hover Hold

Hover hold from the cockpit was disengaged when the pilot moved the controls out of detent. This was "squawked" by the test pilots. It is recommended that the HLH system be mechanized so the pilot can enter the loop without having to re-engage hover hold on the mode select panel. A vernier velocity trim control is recommended. Also, individual axis interrupt should be provided.

Automatic Approach to Hover, Recommendation

The ATC program required the feasibility evaluation of an automatic approach to hover. In this mode, the AFCS programmed a descent and flare to arrive at hover at a predetermined radar altitude. The "canned" program could be flown automatically; i.e., pilot hands off, or manually, where the pilot flew to commands generated in the AFCS and displayed on a flight director. The AFCS drove the flight director in both cases such that the pilot could monitor the aircraft's performance when he was hands off.

As shown in Volume III, the feasibility of such a mode was demonstrated. However, operationally the onboard-generated program has little value. In the experimental program there were no terminal navigation aids. As a consequence there was no system capability to relate aircraft current position to desired hover point. The pilot had to initiate the mode at a gate, particular altitude, heading velocity and position (range from desired hover point). The position gate could only be determined by pilot's visual reference to a predetermined terrain feature.

It is recommended that automatic approach to hover not be incorporated in the production HLH until such time that the ground-based/airborne elements of terminal navigation aids are established.

Hover Trim. Recommendation

Hover trim is a selectable mode which, upon selection, causes the AFCS to fly the aircraft to zero inertial velocity, longitudinal, and lateral. Volume III test data shows the mode function to be feasible. However, the mode is not recommended for HLH. It is recommended that the hover hold mode as previously recommended be used instead. If for any reason, like loss of visual reference to terrain features, the pilot desires zero inertial velocity, he selects hover hold. He is on groundspeed (inertial velocity) hold. Using the groundspeed indicators he can fly to zero easily. Two recommended features enhance the described operation: the vernier speed trim control and the ability of the pilot to enter the hover hold loop without "disengaging" the mode.

DESIGN APPROACH - AFCS

The helicopter airframe is designed to have inherent neutral lateral/directional stability which is achieved by aerodynamic shaping of the fuselage. A delta-3 hinge on the forward rotor causes pitch/flap coupling at the rotor blade with the result that positive longitudinal static stability is provided at all centers of gravity.

Because of these basic airframe characteristics, the aircraft may be flown, "AFCS Off", without handling qualities problems. This reduces the flight safety impact upon the AFCS and allows the AFCS to be located separately from the PFCS at redundancy levels appropriately to the individual modes of operation.

Digital processing is used out of consideration for the accuracy requirements and complexity associated with the flight control computations, sensor coordinate transformations, and compensations. Whole word digital processing is used because the industry's development efforts are given to this rather than incremental.

High quality airframe motion sensors in selected parameters allow the AFCS to achieve precise handling qualities.

Strapdown, skewed inertial sensors are used to provide signals of high accuracy and stability. They give multiaxis redundancy from fewer sensing elements at a much lower cost than gimballed units of the conventional type.

The design of the LCC controller is to be based upon the general approach adopted for the development unit.

MAJOR EQUIPMENT RECOMMENDATIONS - AFCS

The flight control system configuration selected during Task I of the ATC, a direct electrical linkage with an interfacing (not integrated) AFCS, facilitates choosing hardware for the AFCS.

A detail hardware definition was not developed for the AFCS of the production aircraft in the ATC program because of the uncertain timeframe of the production aircraft and the immature status of some very promising developments relating to candidate hardware (computers, sensors - electronic components). It was considered advantageous to allow these more time before making a specification committment.

The main hardware groups which comprise the AFCS are computer complex (input/output processor and computer), sensors, panels (status and control), and LCC controller.

Outputs from the AFCS are communicated to the rotor system by way of the PFCS. Most of these outputs are dispatched to the DEL control units; others are sent to the CCDAs as autopilot commands.

General equipment recommendations for the production HLH are made in the following paragraphs. Volume III of this report describes the AFCS for the ATC demonstrator aircraft. Reference to this work is suggested for typical hardware detail.

Computer Complex

The job required to be done by the digital computer complex is stated typically in the system block diagrams given in Volume III. These indicate the control loops and logic which describe the AFCS mechanization. The best computer specification for the HLH will depend upon the number of systems to be procured, the delivery rate, and the nature of the market offering at the time of need. Trends indicate that a floating point general purpose machine will be most appropriate.

It is recommended that a review of the state-of-the-art and market situation be made in relation to performance requirement close to the time of need. The current military efforts to standardize equipment in this area is of particular relevance.

Sensors

Strapdown Skewed Inertial Sensor

The sensing module of the strapdown skewed inertial sensor is a sensor pair formed by an angular rate gyro and a linear accelerometer. A non coplanar group of three of these modules is used as a working set upon which coordinate transformations are made to derive angular rates and positions, and linear accelerations and velocities in the planes of interest.

Five non coplanar sensing modules are required as a minimum so that a working set remains after the loss of any two by failure. Six in fact, are used on the HLH to give installation and packaging benefits. Also, the interface with the computer-complex is simplified. The six sensing modules are packaged into three sensor assemblies. Each one contains two axis skewed sensor modules with built-in calibration data which is communicated to the computer as an input to the compensation computation.

Precision Hover Sensor

The precision hover sensor provides high resolution along and across position and velocity signals with respect to a selected target. The sensor provides the means by which tight position hold is maintained during hover load acquisition and deposition. Such a sensor was utilized in the HLH/ATC flight demonstrator aircraft, wherein feasibility was demonstrated within the limited scope of the flight test program.

It is clear that the sensor and its associated control loops will need further evaluation and development before it may be considered to be suitable for use on the HLH. The principal deficiencies revealed to date are:

- High cost
- High volume (large)
- High weight
- Uncertainty in "locking-on" particular scenes. (such as grass)
- Operational under a limited range of light intensity only.
- Low reliability

The present precision hover sensor is a gimballed device which develops its position and velocity signals by target scene correlations with similar light intensity details stored for a scene recognized at time zero.

The sensor is designed to operate when the helicopter is flying in the range 25ft-125ft elevation and while undergoing velocities of ± 2 ft/sec in the along, across, and vertical directions. The reference target is unlocked if the limit velocities or the limit position errors are exceeded.

The precision hover sensor is required to operate over illumination conditions ranging from full daylight (10^4 foot-candles) down to an overcast, no moon night (5×10^{-6} foot-candles).

The specification for the precision hover sensor is a demanding one. Because the need for it does not involve a large portion of the HLH total mission, the use of a cooperative device located at the ground target is recommended. By such a means, the weight and cost impact are considerably reduced and the target identification is more certain.

Air Data Sensor

An air data sensor was prepared for the HLH prototype by the Rosemont Corporation (their type 542AK1). Electrical analog outputs of airspeed, barometric altitude, and delta altitude were available. Inputs were pitot and static pressure. This type of sensor is recommended for the production HLH.

Radar Altimeter

A modified Honeywell Corporation APN 194 radar altimeter was used in the design of the HLH demonstrator and HLH prototype. This type is recommended for the HLH production aircraft also. This unit senses vertical distance and velocity.

Spike signals are likely to be emitted from the sensor over some reflecting surfaces, grass being one. This is a problem which is resolved by rejecting the high-frequency content of the signal and reconstituting the signal in a complementary manner using the baro-altimeter. In this application of the APN 194 radar altimeter, it is necessary to use a narrow cone antenna which is canted forward to avoid interferences from a swinging external helicopter load.

Load Controlling Crewman's Controller

The ATC four-axis side arm controller with its "pencil-ball" grip performed satisfactorily in the ATC test and demonstration program. It is recommended that this concept and general design be continued for the production HLH. Minor modifications may be required to increase the control travel to accommodate an increase in the maximum velocity limit for load shuttle tasks.

DEVELOPMENT STATUS

The flight control system recommended in this report is based upon the concepts developed and flight tested within the HLH/ATC program. Volumes II and III of this report provide substantiation for the design.

The ATC program treated fundamental aspects of the FCS design. It yielded the viable system which is described in this document. The system definition was advanced and further particularized by the design activities of the HLH prototype.

The next few paragraphs make summaries and discuss opportunities to further the design status.

DELS

An advanced DELS design for the production aircraft is available from the HLH prototype design, which was made as close to a "production" standard as possible without incurring additional costs.

Stall-flutter damping is included in the production DELS definition but this is subject to a satisfactory flight test evaluation in a prototype aircraft.

The high performance metal film resistors and the light-emitting diodes (LED) used in the DELS showed a susceptibility to failure when subjected to a high humidity environment as imposed during testing to MIL-STD-810B, Method 507, Procedure 1. It is recommended that efforts to provide such components with a satisfactory humidity resistence be emphasized.

Performance of formal electromagnetic interference (EMI)/ lightning hardening tests are recommended to further the design proving.

COCKPIT CONTROL SYSTEM (CCS)

The cockpit control system recommended for the production aircraft is basically that built and evaluated in the ATC program, but some departures from that configuration are made as a consequence of the evaluations which were made of that ATC hardware. These departures are:

- Fixed force feel (not variable)
- Conventional lateral mass balance (not image stick)
- Fail-shutdown CCDA (not single fail-op)

All of these departures from the ATC hardware are simplifications which are considered appropriate to the needs of the HLH. The major effect of these changes upon the status of the CCS is that a redesign of the CCDA will be needed and a force-feel capsule design will have to be generated. Also, an adjustment to the balancing of the lateral controllers will be required. None of these changes are considered to be risk items and thus, no preimplementation action is needed.

AUTOMATIC FLIGHT CONTROL SYSTEM (AFCS)

Intentionally, no emphasis has been given to the definition of the computer complex for the AFCS. The proper time to engage in this work is immediately before the time of need in view of the fluid nature of developments in this field. The same is true for the selection of an inertial sensor.

Because the whole purpose of the HLH is to efficiently handle cargo under a variety of circumstances, any opportunity to further the facilities and techniques should be accepted. The load stabilization system which was evaluated as part of the ATC program was successful but the range of conditions over which it was evaluated was necessarily severely restricted. Also, other approaches to load stabilization, such as the active pendant, are current.

It is recommended that viable methods be competitively evaluated in actual load handling operations. Development of load handling techniques will probably contribute mostly to the improvement in operational efficiency.

Precision Hover Sensor

The precision hover sensor used in the ATC program was specifically designed for that purpose. During the flight testing it was effective in allowing a tight position hold with respect to a selected target. However, the sensor requires much more development work before it may be considered suitable for application. The principal shortcomings of the device at this time are high cost, high weight, and the inability to positively "position lock" onto low contrast scenes. Also, a method of safely reverting from the position hold mode needs to be defined for conditions of sensor failure.

A position hover sensor is not recommended in the production configuration because of the cost and weight incurred and the low utilization in the mission. The velocity hold gives satisfactory performance, except in gusty weather, at which time the accuracy of load placement is reduced.

It is recommended that a target-located cooperative device be considered as an option for use in circumstances when the high-accuracy position hold is essential.

Load Controlling Crewmember Controller

The controller was designed for the HLH/ATC program as a demonstrator. The basic mechanization concepts used were developed for the Apollo hand controls and recent aircraft fly-by-wire development sidesticks.

Careful consideration was given to human factors and to the helicopter environment in the design.

Evaluations during the ATC flight tests were complimentary to the controller. Its performance is considered to be satisfactory in its present form.

Design for production quantities and for use in the production aircraft will be required at the proper time.

REFERENCES

1. ADVANCED TECHNOLOGY COMPONENT PROGRAM FLIGHT CONTROL SYSTEM - TASK 1, PART 1, SUMMARY REPORT, Report No. D301-10095-1, Boeing Vertol Company, Phildelphia, PA.

2. STATEMENT OF WORK FOR THE ADVANCED TECHNOLOGY COMPONENT PROGRAM, ATC Contract No. DAAJ01-71-C-0840(P6A), U. S. Army Aviation Systems Command, St. Louis, MO, June 1971.

3. HEAVY LIFT HELICOPTER PRIME ITEM DESCRIPTION DOCUMENT, S301-10000, U. S. Army Aviation Systems Command, St. Louis, MO.

4. AIR SYSTEMS REQUIREMENTS DOCUMENT FOR THE HEAVY LIFT HELICOPTER, U. S. Army Aviation Systems Command, St. Louis, MO.